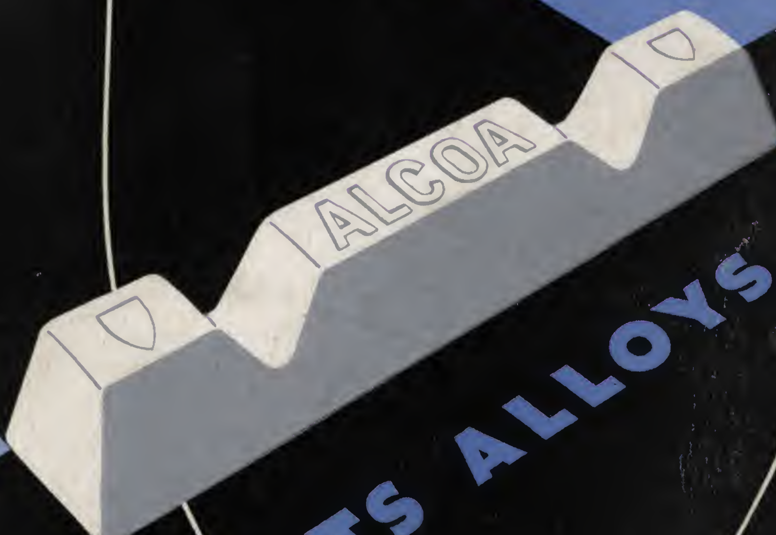
ALCOA.

ALUMINUM AND ITS ALLOYS



1946★

ALCOA

aluminum

★ *Second Printing with Minor Corrections*

and its

ALLOYS

ALUMINUM COMPANY OF AMERICA

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contents

Page

general information 9

physical properties 15

Specific gravity 15
Electrical conductivity 15
Thermal conductivity 16
Thermal expansion 16
Modulus of elasticity 16
Mechanical properties 17
Effect of temperature on mechanical properties 19

chemical properties 19

Resistance to corrosion 22

wrought alloys 29

Tempers and temper designation 29
Choice of alloy 33
Nonheat-treatable alloys 34
Heat-treatable alloys 35

wrought products of aluminum alloys 39

Alclad products 41
Forgings 42
Impact extrusions 44
Extruded shapes 44
Screw machine products 45

heat treatment of wrought aluminum alloys 45

Annealing aluminum alloys 49
Solution heat-treatment practice 50
Precipitation heat-treatment practice 55

aluminum alloy castings 57

Designation 57

types of castings 58

Sand castings 59
Heat-treated sand castings 61
Permanent-mold castings 64
Die castings 67

design of aluminum alloy castings 67

fabricating practices 71

Forming 71
Hot forming 75
Welding 77
Resistance welding 79
Brazing 79
Machining 80
Riveting 81
Painting aluminum alloys for protection 82

tables .... *See Index to Tables, pages 86 and 87*

index 155

foreword

Many of the alloys included in this booklet, their processes of fabrication or casting, their heat treatment, or the products of one or more of these operations are covered by United States patents.

The number of alloys of aluminum has grown to such an extent that the designing engineer is sometimes at a loss to know which one to choose. No two of the alloys have identical properties, and for each application some one alloy is best suited. It is also necessary to know the forms in which these materials are available and the sizes that are in commercial production.

It is the purpose of this booklet to present in concise form some of the fundamental information concerning the alloys of Alcoa Aluminum which are produced by Aluminum Company of America.

Mining aluminum ore (bauxite).

general information

Aluminum is produced by an electrolytic process discovered only a little more than fifty years ago. The spectacular development of the industry since then results from the metal's diversity of properties which has made possible a great variety of applications. A wide range of peace-time uses existed before World War II, but the requirements of war itself further emphasized the importance of this interesting and useful metal.

The most striking quality of aluminum is its lightness; comparing equal volumes, it weighs only about one-third as much as most of the other commonly used metals. However, many other properties contribute to its choice, and often the happy combination of several desirable characteristics makes aluminum the economical material to use. Chief among the qualities which are possessed by aluminum in outstanding degree are: resistance to the corrosive action of the atmosphere and of a great variety of chemical compounds; thermal and electrical conductivity; reflectivity for radiant energy of all wave lengths; and ease of fabrication. Aluminum is welded by all commercial methods, and it is economically finished in a wide range of textures and colors.

The fact that its compounds are colorless is of outstanding advantage in certain of its applications, particularly in the chemical and architectural industries. At high temperatures,

A step in the wet chemical process for obtaining alumina, or aluminum oxide, from bauxite. The alumina is later reduced to aluminum.

or in the presence of certain chemicals, notably strong alkalis, aluminum is a powerful reducing agent and is used to reduce refractory metals from their ores and to deoxidize molten steel. The fact that aluminum is non-toxic, non-magnetic and non-sparking influences its use for many products.

Comparisons of costs should be made on the finished article as made from the different possible materials, not on their relative prices per pound. Since the volume of metal is usually substantially the same, the price per pound of aluminum should be divided by the ratio of specific gravities (approximately three for most of the common metals) when comparing the material costs. In addition, economies frequently result from the greater ease with which aluminum can be fabricated, polished or otherwise finished, and also from the lower cost of distribution made possible by the lightness of the metal.

Frequently, these economies are more than sufficient to overcome an unfavorable cost comparison from the standpoint of metal value alone, as, for example, with common grades of steel. In such comparisons, the higher scrap value of aluminum, when the article is finally discarded, is always an advantage to be considered in the choice of the metal.

Although commercially pure aluminum in the annealed or the cast condition has a tensile strength only about one-fourth that of structural steel, the strength can be markedly increased by cold working the metal. This gain in strength is accompanied by a loss in the ductility; the ease of forming is decreased as the amount of cold working is increased.

"Aluminum" is used here in its popular sense, that is, to include not only commercially pure aluminum but also the light alloys in which aluminum is the principal constituent.

The addition of other metals to form alloys offers another means of increasing the strength and hardness of aluminum. Even the small percentage of impurities in commercial aluminum is sufficient to increase the strength, compared with that of the pure metal, by about 50 per cent.

The metals most commonly used in the production of commercial aluminum alloys are copper, silicon, manganese, magnesium, chromium, iron, zinc and nickel. These elements may be added singly, or some combination of them may be used to produce the desired characteristics in the resulting alloy. If the alloy is to be manufactured in wrought forms, the total percentage of alloying elements is seldom more than six or seven per cent, although in casting alloys appreciably higher percentages are frequently used.

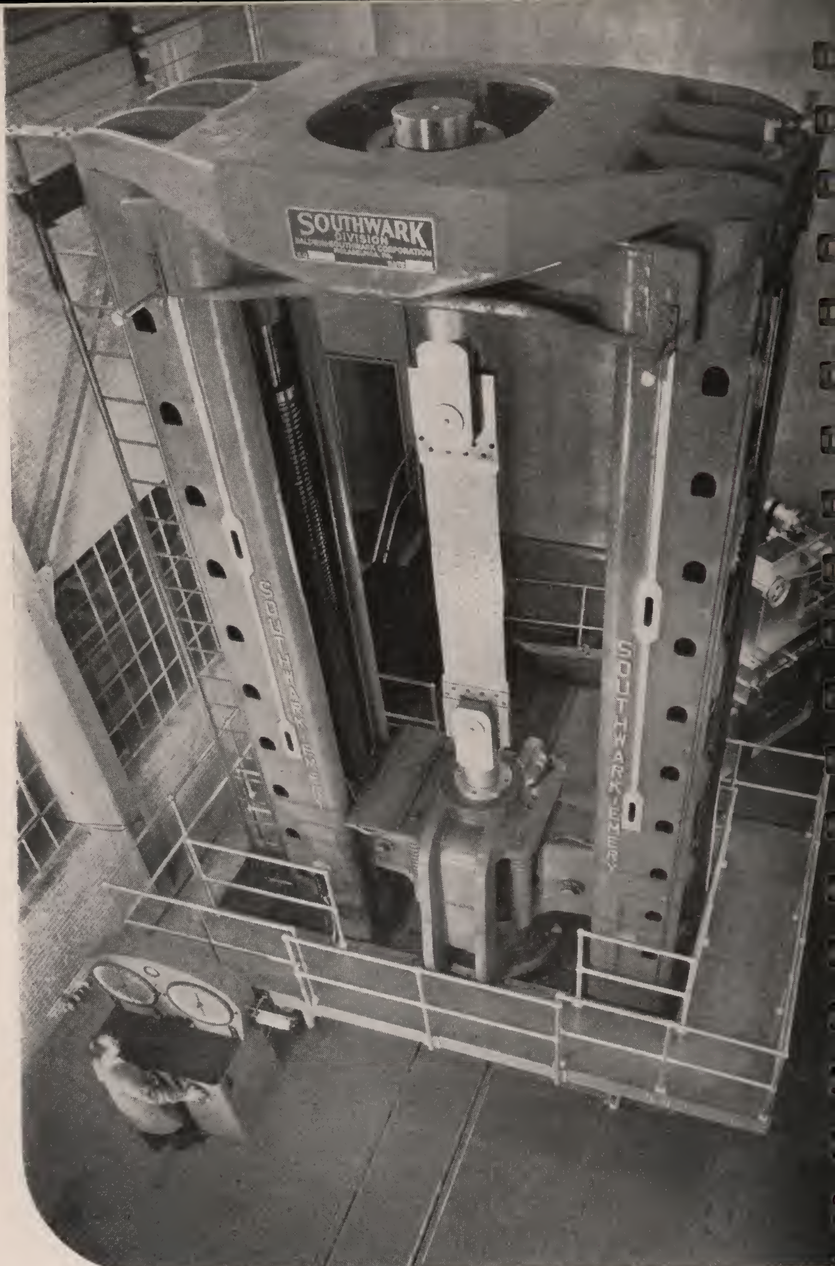
The tensile strength of the aluminum alloys in the cast or the annealed condition varies, depending on their composition, up to values about double that of commercial aluminum. The wrought alloys may have their strength further increased by cold working. The gain in strength which results from alloying and strain hardening is accompanied by a decrease in the ductility, although the forming properties which result are more than adequate for a great variety of commercial uses.

Some years ago, the discovery was made that certain of the aluminum alloys, when subjected to appropriate heat-treatment processes, show remarkable increases in tensile and yield strength, and hardness. (The elongation in many instances is also increased over that of the annealed alloy.) The combination of alloying and heat-treatment processes has made available a series of aluminum alloys having strengths comparable with or higher than those of ordinary steel, while retaining in large measure the characteristic qualities of the parent metal. Both wrought and cast alloys which respond to the heat-treatment operations have been developed, but the improvement is more pronounced in the case of the alloys in which the cast structure has been broken up by working the metal. The development of this class of alloys has made possible the addition of "excellent mechanical properties" to the list of desirable qualities of aluminum.

The change in strength which is accomplished by the alloying of other metals with aluminum is accompanied by changes in the other properties of the metal. These changes are seldom, if ever, the same in the different alloys, with the result that several alloys may have substantially the same tensile strength but differ widely in yield strength, ductility, thermal and electrical conductivity, the ease with which they can be cast or fabricated, or in other qualities upon which their various applications depend. In fact, for many purposes, considerations other than strength are the deciding factors in the choice of the material. There is little sacrifice in the property of lightness in the commercial alloys of aluminum; with few exceptions the increase in specific gravity does not exceed three per cent, and several alloys are slightly lighter than pure aluminum.

The properties which are required in a material, as well as the qualities in which some sacrifices may be made without serious handicap, vary widely with the use that is to be made of it. A considerable number of commercial alloys have been developed, each of which is designed to meet the requirements of a certain type of application. The compromise which is usually necessary in choosing any material is thus reduced.

The ease of manufacture varies with the nature of the commercial manufacturing process. For example, some alloys having valuable properties may be readily rolled into plate and sheet, but present difficulties in the manufacture of tubing or forgings which would make their cost prohibitive. Other alloys have been developed primarily to overcome such manufacturing problems, and are fabricated only in the forms for which they were designed. While aluminum alloys having a wide range of mechanical properties are available in practically all the forms in which metals are manufactured, not all of the alloys are available in all of these forms. The table of Standard Commodities of Wrought Alloys, page 89, indicates the alloys regularly manufactured in the various wrought forms. In some instances, other alloys can be produced where required. Such cases should be taken up with a sales representative of Aluminum Company of America.



Powerful testing machine, Aluminum Research Laboratories.

physical properties

specific gravity

Aluminum of commercial purity weighs 0.098 pound per cubic inch, corresponding to a specific gravity of 2.71. Data for the Alcoa wrought alloys are shown in Table 9 and for the cast alloys in Table 10. For purposes of approximation, it may be remembered that aluminum, including its alloys, weighs a tenth of a pound per cubic inch.

electrical conductivity

Aluminum has a high electrical conductivity; the manufacture of cable and bus bar for the transmission of electric power constitutes one of the large uses of the metal. This property is lowered by the addition of other metals, the amount of the reduction varying with the nature and amount of the added element. Practically pure aluminum has a volume conductivity in excess of 64 per cent of the International Annealed Copper Standard, but because of its low specific gravity, the mass conductivity is more than 212 per cent. Commercial aluminum conductors are made from aluminum of such purity that the conductivity is not less than 61 per cent. The values for the wrought alloys of Alcoa Aluminum are shown in Table 9 and for the cast alloys of Alcoa Aluminum in Table 10.

Elements in solid solution cause much greater decrease in electrical conductivity than when they are present as undissolved constituents. Alloys containing hardeners, which, like silicon and copper, change greatly in solid solubility with rise in temperature, show corresponding variations in conductivity, depending on their rate of freezing and previous thermal treatment. This fact should be considered, particularly in the case of castings supplied in the "as-cast" condition.

thermal conductivity

Aluminum of a purity of 99.6 per cent has a thermal conductivity of 0.52 in c.g.s. units (calories per second, per square centimeter, per centimeter of thickness, per degree centigrade), which is equivalent to 1,509 B.t.u. per hour, per square foot, per inch of thickness, per degree Fahrenheit. The thermal conductivities of some of the aluminum alloys are shown in Tables 9 and 10.

thermal expansion

The coefficient of thermal expansion of aluminum is slightly more than twice that of steel and cast iron (see Table 11). The alloys have coefficients the same or slightly less than that of pure aluminum, except those which contain relatively high percentages of silicon, in which the value is appreciably lowered. In spite of the difference in expansion when subjected to thermal changes, composite structures of steel and aluminum alloys show entirely satisfactory performance.

modulus of elasticity

The modulus of elasticity, which is the ratio of stress to strain in the elastic range, varies somewhat, depending on the composition of the material; in general it increases with increasing amounts of alloying elements from about 10,000,000 to about 10,600,000 pounds per square inch. For practical purposes however, the modulus may be taken as 10,300,000 pounds per square inch.

Because of the lower value of this constant as compared with that of steel, it is necessary to use deeper sections in aluminum alloys in order to maintain the same deflection characteristics when they are loaded as beams. Such redesign can be accomplished to produce a structure having the same deflection under load and actually higher ultimate strength than would be obtained with structural steel, and, at the same time, to realize a saving in weight of more than a pound for each pound of aluminum alloy used.

The lower modulus of elasticity is an asset when impact loads are to be resisted, since, other things being equal, the lower the modulus, the greater the ability to absorb energy without permanent set. The lower modulus is also advantageous in reducing stresses produced by misalignment, settlement of supports, or other fixed deflections, accidental or intentional.

The modulus of rigidity is 3,850,000 pounds per square inch for aluminum and its commercial alloys, corresponding to a value of 0.33 for Poisson's Ratio.

mechanical properties

Typical mechanical properties of aluminum (2S) and of the various wrought alloys of Alcoa Aluminum are shown in Table 12. Similar data for separately cast test bars of the more common casting alloys are included in Tables 13, 14 and 15. These values may be used in comparing the alloys with each other, or with other materials, since typical properties are commonly quoted, but it is important to recognize that the values for different commodities may vary somewhat from these typical values either because of the size, shape, method of manufacture, or type of test specimen used for that product.

Purchase specifications are based on the minimum values for those properties which are regularly determined in the routine control of commercial manufacturing operations. Tables showing these minimum properties which can be guaranteed are included at the end of the booklet.

It will be observed that the minimum properties guaranteed for an alloy are not the same in all commodities or in all sizes of a given product. Since the type and dimensions of the

Forged aluminum alloy propeller blades.

test specimen specified by standard testing practices vary with the nature of the product or with its dimensions, some of the variations in the guaranteed properties represent differences inherent in the test rather than fundamental differences in the properties of the metal in the various commodities.

EFFECT OF TEMPERATURE ON MECHANICAL PROPERTIES: In common with other materials, the tensile strength, yield strength and modulus of elasticity of aluminum alloys are lower at elevated temperatures than they are at ordinary temperatures. The elongation usually increases as the temperature is raised until at a temperature a little below the melting point it drops nearly to zero. This corresponds to the "hot-short" range of the metal.

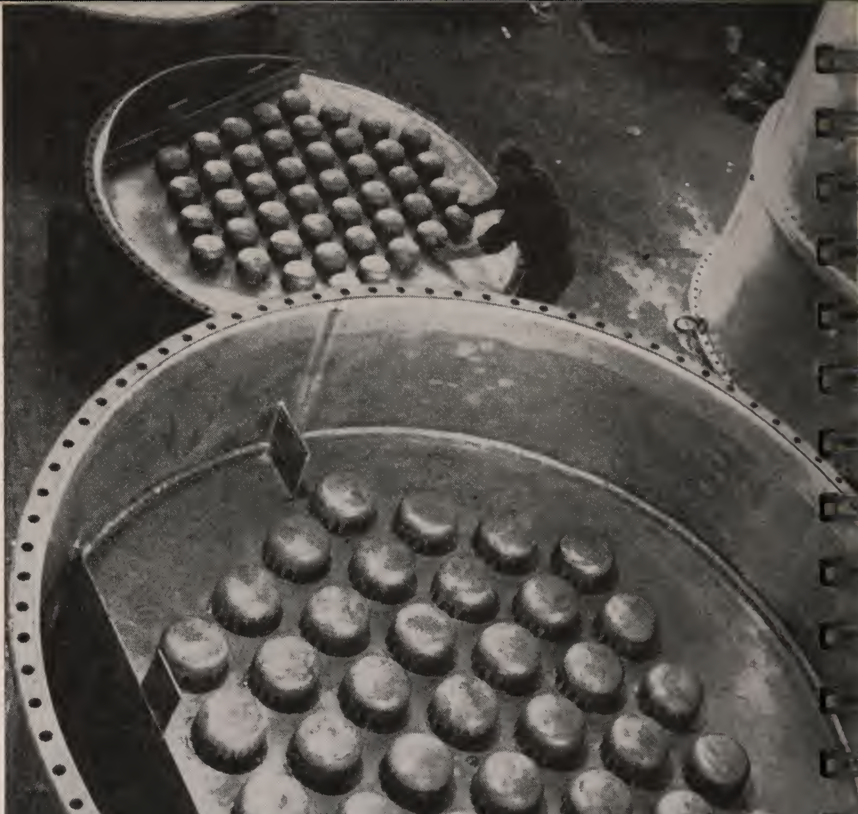
Tests made at −114°F. show strengths and elongations higher than those obtained at ordinary temperatures.

In Table 16 are shown the tensile properties of a number of Alcoa alloys, both wrought and cast, as determined at elevated temperatures. These data were obtained by storing a sufficient number of specimens at each testing temperature to permit tests to be made after increasing intervals of time. When successive tests gave the same results, the properties were considered to be representative of the alloy in equilibrium at the temperature of the test.

chemical properties

The resistance of aluminum to the attack of a variety of chemicals is explained by its property of forming a thin, firmly adherent coat of oxide over its surface, which prevents further action.

A number of commercial chemicals are produced, stored or shipped in aluminum equipment. Concentrated nitric and acetic acids used in the textile industry are handled in alu-



Aluminum is extensively used for chemical equipment.

minum, not only because of the long life of the metal, but also because any compounds introduced by superficial attack are colorless. For the same reasons, gums and resins used in clear varnishes and lacquers are processed in aluminum.

Aluminum tank cars make possible bulk shipments of concentrated solutions of hydrogen peroxide, because its decomposition is not catalyzed by aluminum compounds.

Numerous fermentation reactions are carried out in aluminum equipment because its compounds do not poison the yeasts or other organisms which cause the reaction to proceed.

Its resistance to attack and the fact that its salts have no harmful action on the human system account for the wide use of aluminum in the processing and preparation of foods and beverages.

Strong alkalis dissolve aluminum oxide as well as the metal and thus remove the protective film from its surface, permitting chemical action to proceed till the metal is destroyed. However, many solutions having a mildly alkaline reaction are used successfully in contact with aluminum, particularly if an inhibitor is present. Many moderately alkaline washing powders and metal cleaners are marketed with additions of sodium silicate which make them safe for use in contact with aluminum.

Gaseous compounds of sulphur are without harmful action on aluminum. The successful use of the metal for architectural purposes in industrial centers gives evidence of this fact. Similarly, much of the equipment in plants for the manufacture of rayon is of aluminum, because of its resistance to attack by compounds of sulphur which are so harmful to most commercial metals. In both of these applications, the fact that the compounds formed by superficial action are colorless is of outstanding importance.

Use is made of the chemical properties of aluminum in the deoxidation of molten steel and in the reduction of some of the refractory oxides to produce metals such as vanadium.

Advantage is taken of the high heat of reaction of aluminum in reducing iron oxide in the Thermit welding process.

resistance to corrosion

The resistance of a material to corrosion is a relative term and depends on a comparison with other metals or with other alloys of the same metal. None of the commercial metals is immune to all conditions to which structural materials are exposed. There is always the possibility of overstressing the dangers of corrosion with the result that the prospective user is deterred from employing the metal where there is no occasion for concern. On the other hand, if the possibility of trouble is ignored, metal failures may result which could have been avoided by simple protective measures.

Commercial aluminum contains, as a maximum, one per cent of impurities. This metal, designated 2S when in the wrought condition, is widely used because of its high resistance to ordinary conditions of exposure. Selected grades of higher purity are even more resistant to most forms of attack. The addition of other elements to produce alloys from commercial aluminum does not usually improve the resistance of the metal, and in most cases causes some loss in this property. Magnesium, manganese and chromium have no adverse effect, and silicon has but little.

All of the commercial aluminum alloys are properly classed as materials resistant to corrosion, although some are more resistant than others, and hence are chosen for those applications in which this property is of major importance.

Alloy 3S has practically the same resistance as 2S to the atmosphere and to salt water. Alloy 52S appears to be more resistant to salt water than 2S, from the standpoint of the retention of both its mechanical properties and its appearance.

Considerable study has been made on the effect of the temper of these alloys on their resistance to attack. In general, it may be stated that any differences in this property as a result of strain hardening are less than the small differences which are normally to be expected from one lot to another of commercial materials.

These alloys are generally used without any protection other than the usual precaution to avoid electrolytic action from contact with a dissimilar metal. Under severe conditions of exposure, such as may prevail on shipboard, or where the metal is continually in contact with wood or other absorbent material in the presence of moisture, protective paint coatings are desirable as an added precaution. (See page 82.)

The heat-treatable alloys can be divided into three general groups with respect to their resistance to corrosion. One group consists of the alclad materials (see page 41); a second includes 53S and 61S, and the third is composed of alloys such as 14S, 17S, 24S and 75S.

The heat-treatable, high-strength alloys in the form of alclad sheet have a resistance to corrosion, which, although it varies somewhat with the alloy and heat treatment, approaches that of alloys 2S and 3S. Excessive diffusion of alloying elements from the core into the coating, resulting from unnecessarily long heat treatments, particularly if the material has been quenched slowly, may considerably reduce their high resistance to corrosion. For this reason, thin alclad sheet should be heat treated for the shortest time consistent with obtaining the desired mechanical properties, should be quenched rapidly and should not be reheat treated more than once or twice. Artificial aging of Alclad 24S, to develop the maximum strength, also reduces the resistance to corrosion somewhat, although the artificially-aged material still retains a resistance to corrosion at least comparable with that of properly quenched 24S. For those applications where sheet combining a high strength and a high resistance to corrosion is required, alclad materials should be used. In most cases, additional paint protection is not required even in rather severely corrosive locations except at faying surfaces or where the metal is in contact with absorbent materials, such as wood or certain types of insulating materials.

The alloys 53S and 61S behave very similarly under corrosive conditions, although the former is slightly superior to the latter in salt water or marine atmospheres. Both compare favorably with 2S in most atmospheres, but are not quite the equivalent of 2S in some chemicals. As with 2S, 3S and 52S, their resistance to corrosion is not significantly affected by the temper, nor is it reduced to an undesirable extent by a relatively slow quench. Where the high strengths obtainable with alclad sheet of the strong alloys are not required, or where a high resistance to corrosion is desired in a commodity not available in alclad form, these alloys represent a wise choice.

The high-strength alloys, while they are more susceptible to losses in mechanical properties when exposed to corrosive conditions than are 53S and 61S, are still to be classed as resistant materials. Tests of standard structural shapes of 17S alloy, for example, showed insignificant loss in strength after an exposure of a year along the seacoast; after four years, the losses were only slightly greater, indicating that the attack tends to be self-stopping. Regardless of this, however, it is usually recommended that these alloys be protected, as by anodic oxidation or painting, if they are to be used in the more corrosive atmospheres. In milder locations, protective coatings are often not necessary unless superficial surface attack is objectionable. In contrast to the other alloys, however, the resistance to corrosion of these high-strength materials is related to the temper and is affected adversely by improper quenching or by reheating. Generally speaking, the highest resistance to corrosion is secured with material which has been quenched rapidly after the solution heat treatment; slow quenches or reheating for more than a short time at temperatures of several hundred degrees Fahrenheit may result in a rather poor resistance to corrosion. For that reason, hot riveting, hot forming and fusion welding of these alloys are not usually recommended unless the assembly can be subsequently heat treated. The resistance to corrosion of these alloys in the annealed temper is not particularly good, but their strengths in this temper also are low and, hence, annealed material is used only when a severe forming operation must be carried out and the finished part is subsequently heat treated.

Although artificial aging treatments involve reheating of quenched materials, and may reduce the resistance to corrosion of these alloys, the use of suitable artificial aging treatments on 14S and 24S does not have this undesirable effect. Tests have shown, for example, that the losses in tensile strength of 24S resulting from corrosion are quite high if the material has been aged for an hour or so at about 375°F. to 400°F. but are no greater than those of rapidly quenched 24S-T when aging periods of some 5 to 10 hours at these temperatures are used. Thus, 24S-T (and Alclad 24S-T) offers considerable advantage when hot forming is necessary, since further heating after the hot forming has been completed will "bring back" the resistance to corrosion (and increase the strength).

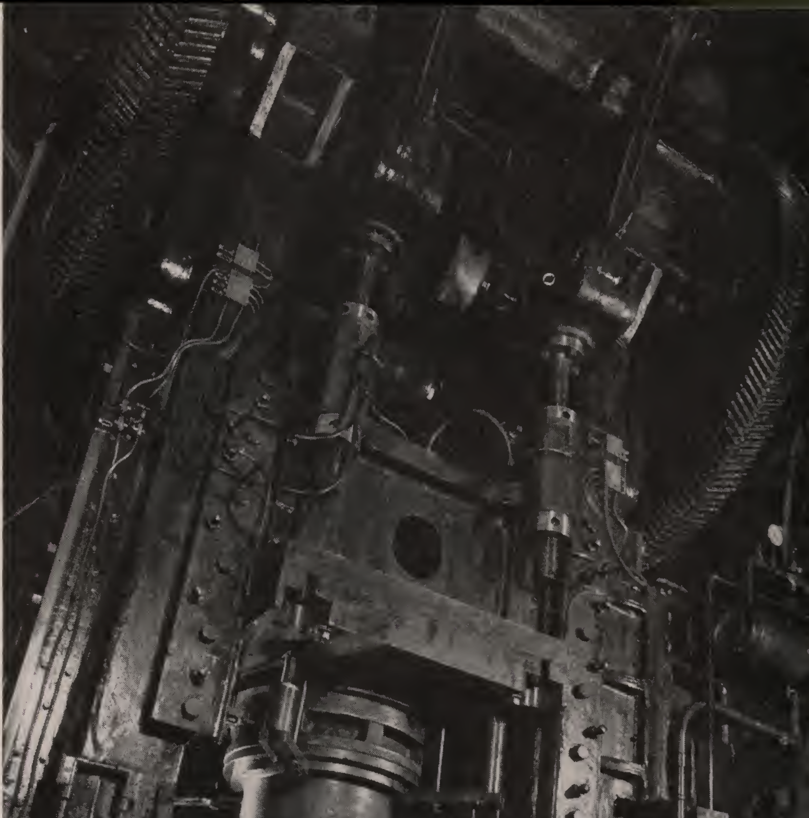
The resistance to corrosion of 75S and Alclad 75S is very similar to that of 24S and Alclad 24S, respectively, and essentially the same effect of heat treating and quenching variables apply. Reheating 75S-T for several hours at about 350°F., however, does not adversely affect the resistance to corrosion.

Another factor bearing on resistance to corrosion, or on the practical effect of corrosion, which must be considered is that of thickness or bulk. A depth of attack which may result in the perforation of thin sheet, for example, may be no more than a superficial surface film on a thick plate, a bulky casting, or a large forging. For this reason, it may often be possible to use a casting or forging alloy of rather low inherent resistance to corrosion without applying protective coatings under conditions which would suggest the use of a protective treatment on sheet of even the best alloy. In 14S-T, the effect of bulk or thickness also is important, but for a different reason. This material, unlike 14S-W, 17S-T and 24S-T, appears to develop a better resistance to corrosion if given a mild quench than if quenched very rapidly in cold water. Because of this, the heavier sections (as a result of the unavoidably slower rate of cooling even in cold water) retain a high resistance to corrosion, and are superior to the same sections in 14S-W, 17S-T and 24S-T quenched as rapidly as is possible.

In summary, then, rapid quenching and protective coatings are desirable for 17S, 24S and 75S, and hot forming, hot riveting, welding and reheating are generally to be avoided, especially for thin sections. When hot forming is necessary, 24S is recommended and the formed part should be artificially aged. For bulky sections, 14S-T offers attractive characteristics. If a combination of high strength and high resistance to corrosion is important, Alclad 24S and Alclad 75S are good choices, while if lower strengths can be accepted, 53S and 61S provide corrosion resistant products. Protective coatings are desirable in severely corrosive atmospheres and can be omitted in the more mild exposures, almost irrespective of alloy, but are more important on thin than on thick sections. Contact with dissimilar metals, other than zinc, is to be avoided. Paint coatings should be applied to faying surfaces and to surfaces in contact with absorbent materials. For the storage and handling of food products and chemicals, 2S, 3S or high purity aluminum is to be preferred.

Among the cast alloys there are similar differences in resistance to corrosive environments. Under most exposures the alloys in which magnesium is the alloying agent (214 and 220 and die-cast alloy 218) show the least attack. Only slightly less resistant are the alloys in which silicon or silicon and magnesium are the hardening elements: 43, 47, 356, B214 and die-cast alloys 13 and 360. The alloys in which copper or nickel are present in substantial percentages show less resistance to severely corrosive environments.

While all of the aluminum alloys in commercial use are resistant to corrosion, they are not all equally resistant. Whether they should be given protection treatment depends upon the alloy and the type of service it is to perform. The least resistant of these will last indefinitely in most interior applications whereas the most resistant should be protected in certain exposures as an added precaution.



"Capping" aluminum beer barrel half in a 450-ton press.

wrought alloys

In the production of the wrought products an ingot is first cast in the size and form best suited for the fabricating equipment on which it is to be processed. The ingot is then worked hot in order to break down the cast structure under conditions of maximum plasticity. It may be reduced to its final dimensions without cooling, other than that which normally occurs during the fabricating process, or the final working may be done cold.

tempers and temper designation

As the metal is cold worked it becomes strain-hardened, the increase in strength and hardness depending on the amount of reduction which it receives. If it is subsequently heated to its annealing temperature, the effects of cold working are removed and the metal is in its soft temper, designated by the symbol "O" following the alloy designation, which in the case of Alcoa wrought alloys is a number followed by the letter "S" (2S). A letter preceding the alloy symbol indicates a minor change in composition from that of the basic alloy.

In one class of alloys, the strain-hardening process is the only means of increasing the tensile properties. The alloys 2S, 3S and 52S are of this type, and their various tempers are produced by subjecting them to definite reductions by cold work after they have been annealed during their fabrication.

The hard temper, designated "H," is defined by the tensile properties which result from the maximum amount of cold working which it is practicable to perform with commercial fabricating equipment.

Tempers intermediate between the soft and the hard temper are produced by varying the amount of cold work by proper choice of the thickness at which the metal is given its last annealing. The tempers are designated by the fractional symbols "¼H," "½H" and "¾H," indicating an increase of the strength of the annealed alloy by the corresponding fraction of the spread between the soft and the hard tempers.

These alloys (2S, 3S and 52S) are available in definite, controlled tempers other than soft "O" only in those commodities which are normally produced by cold work from the hot mill slab or bloom. The products which are included in this classification are sheet, tubing and wire. Bar, rod, plate and shapes (both rolled and extruded) are finished directly from hot ingots and are normally supplied "as-fabricated." Bar and rod may be hot worked slightly oversize so as to permit a cold finishing operation, but this is done only to improve surface finish and dimensional accuracy. The amount of cold working during cold finishing is not sufficient to cause material change in the mechanical properties of the alloy, nor is the stock annealed before it is cold finished so as to permit a definite control of the temper.

During the hot-working process the metal cools gradually; the smaller the size of the finished product, the lower is the finishing temperature. There is consequently a variable amount of strain hardening of "as-fabricated" commodities; heavy sections are in practically the soft temper while thin sections may have properties approximating those of the half-hard temper. Different lots of the same material (that is, the same size, shape and alloy) show reasonable uniformity of properties because of the standardization of the manufacturing processes.

In another class of wrought aluminum alloys, improved mechanical properties are produced by heat treatment or by a combination of heat treatment and strain hardening.

The heat treatment of aluminum alloys is a two-stage process, comprising a solution heat treatment at high temperatures and a precipitation treatment at room or slightly elevated temperatures. The solution heat treatment considerably increases the strengths, as compared to annealed material. In most of the wrought alloys, subsequent aging or precipitation at room temperature causes a further increase of upwards of 10,000 pounds per square inch in the tensile and yield strengths as compared with the values immediately after quenching. Further aging at elevated temperatures, except in a few alloys, produces an additional marked increase in the yield strength, with some increase in the tensile strength and a considerable decrease in the elongation. In general, the same properties are developed whether or not the high temperature aging is preceded by aging at room temperature. In some alloys, such as 24S, the effect of high temperature aging is increased by introducing some cold work into the material after the solution heat treatment and before the high temperature aging.

When the heat-treatable aluminum alloys were being developed, it was recognized that the strengths of some of them were considerably increased by artificial aging, but it was not at first realized that alloys of the 17S and 24S type responded in a similar manner to the elevated temperature treatments. As a result, the room temperature aged tempers of these alloys and the artificially aged tempers of the alloys like 14S, 53S and 61S both were considered to represent "fully-aged material" and the temper was designated by the letter "T." For those alloys which were known to respond to artificial aging, the temper resulting from aging at room temperature after the solution heat treatment was designated by the letter "W."

More recently it has been recognized that the strength of 24S which has fully aged at room temperature can be increased

Rolling aluminum foil.

further by suitable artificial aging treatments, so that the temper which has for some years been designated as "T" properly should be called "W." Since changing the designation at this late date would result in considerable confusion, the designation "T80" has been adopted for 24S which has been heat treated and artificially aged. To indicate the different levels of strength which result in aged material which has been cold worked in varying amounts prior to aging, the designations "T81," "T86," etc. are employed, each indicating a different amount of cold work.

Since it also is possible to increase the yield strength of 17S-T and 24S-T to a marked degree by cold work alone, this temper is designated by the symbol "RT." When a similar practice is employed on a material commercially available in the "W" temper, the cold-worked material is designated by the symbol "T3" (i.e., 11S-T3).

Some alloys, when produced by certain manufacturing methods, retain sufficient alloying material in solid solution to show some improvement in tensile properties, if they are artificially aged without first being solution heat treated. The temper resulting from such a practice is designated by the symbol "T5."

choice of alloy

While there is no limit to the number of alloys of aluminum that might be produced, commercial manufacturing considerations make it necessary that the number shall be as small as possible and still provide the necessary combinations of properties to meet the needs of industry. Even so, the list may appear formidable to the reader who is not familiar with the developments in the use of the light alloys. The tables at the end of the booklet list the mechanical properties of the alloys of Alcoa Aluminum produced by Aluminum Company of

America. A brief discussion of these alloys may be helpful in the selection of the most suitable material.

The choice of alloy for a particular product depends upon which of the qualities is most essential for the intended use. The determining factor may be maximum mechanical properties or resistance to corrosion; ease of machining, welding or forming; or minimum cost of material. Some limitation is set by commercial availability. Certain of the alloys, for example, are available in a wide variety of commodities; others, because of their characteristics or because they were developed for a special purpose, are available only in a few forms. The commercial forms in which the wrought alloys of Alcoa Aluminum are regularly produced are indicated in Table 1.

nonheat-treatable alloys

For many purposes the strengths of 2S and 3S are entirely adequate and their use offers the advantage of lower cost and of greater ease of fabrication than would be the case with the harder alloys. For some applications the greater strength of 3S gives it preference over 2S in spite of the somewhat greater ease of forming the latter alloy. These materials find use in the manufacture of cooking utensils, bottle and jar closures, chemical equipment and for architectural purposes. In fact, they have the most general use of any of the alloys for nonstructural applications. They are produced in the widest range of sizes, and in some products closer dimensional tolerances can be maintained.

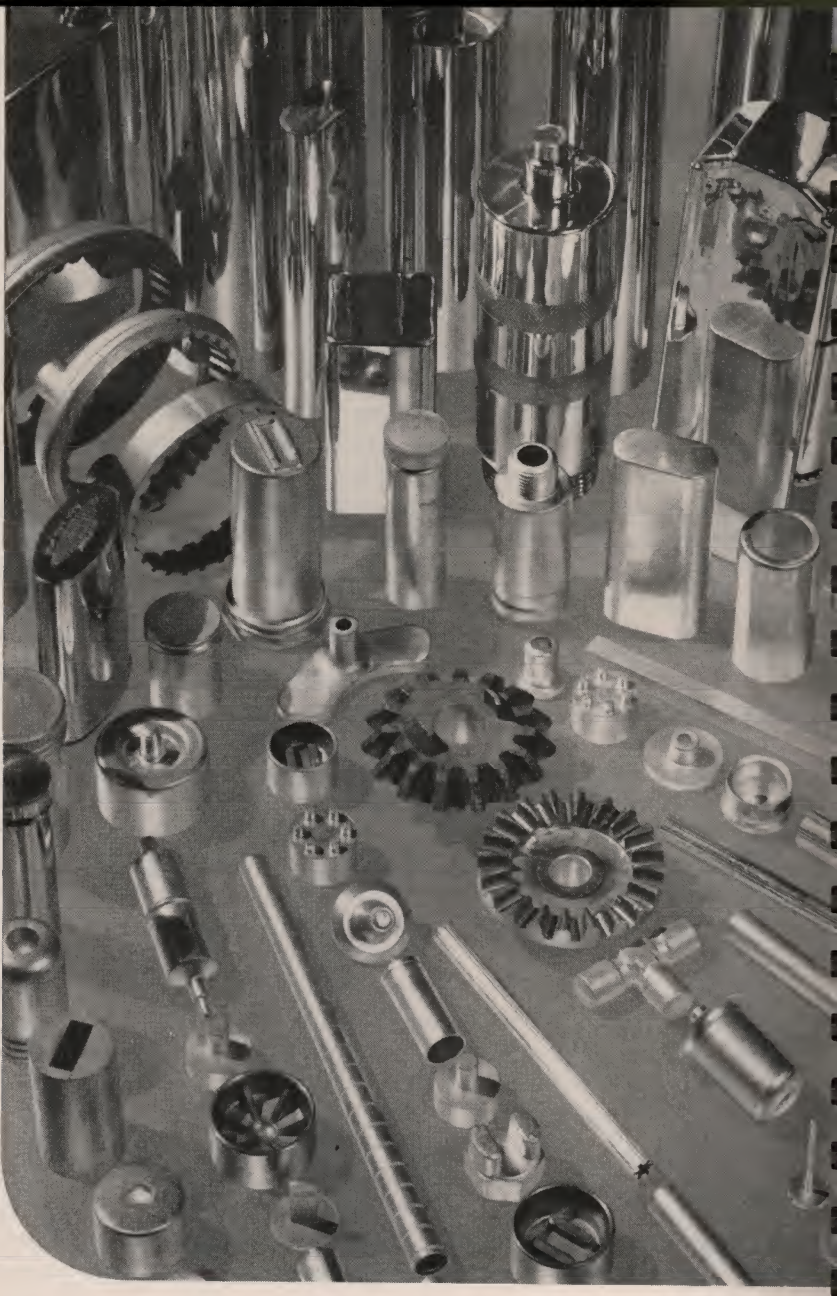
The alloy 52S has tensile and yield strengths about double those of 2S and 3S in corresponding tempers, but only about half those of the high-strength alloys 24S and 75S. For that reason, it cannot be formed quite so readily as 2S and 3S in similar tempers, but it is somewhat superior in this respect to the high-strength heat-treatable alloys. Since, however, increased strengths resulting from strain hardening are accompanied by a decrease in workability, it is sometimes possible to secure from a softer temper of 52S equal strengths combined with greater workability than can be obtained with 2S or 3S. In addition, 52S is characterized by a high endurance limit and an especially high resistance to corrosion by salt water and marine atmospheres.

Alloy 56S is now available only in the form of wire (including flattened wire, and flattened and slit wire). The various tempers of this alloy are produced by strain hardening, yet its mechanical properties are quite comparable with those of the heat-treated alloys. In the soft temper its tensile strength is greater than that of 53S-T, while in the hard temper its strength compares with that of 17S-T.

heat-treatable alloys

The oldest of the heat-treatable alloys is 17S, developed some 30 years ago. Although it now has largely been replaced by 24S for those uses in which high strengths are required, it still is available in a variety of commodities and finds many uses where light weight materials with a strength comparable to that of steel will suffice. It has a good resistance to corrosion in the heat-treated temper (17S-T), can be machined and formed comparatively easily and, because it age hardens at a slower rate than 24S, is somewhat superior to the latter alloy when forming soon after heat treatment is necessary. This latter characteristic makes it a good alloy for rivets, since it facilitates driving large rivets.

The alloy 24S is quite similar to 17S in composition and in many of its characteristics and, until recently, was the strongest aluminum alloy commercially available. An even higher strength material (75S) is now available in some forms but has not yet attained wide use. As indicated by Table 1 of the



Products produced by impact extrusion and press forging.

appendix, 24S is available in practically all commercial forms and, in the form of sheet and plate, is available as an alclad product. Because of their high strengths, 24S and Alclad 24S are today the principal alloys used in the production of aircraft.

Like most of the other heat-treatable alloys, 24S age hardens to a considerable extent at room temperature following heat treatment. Cold working the material after heat treatment further increases the tensile and yield strengths with some sacrifice in ductility, but without loss in the resistance to corrosion. Artificial aging treatments, particularly if applied to materials which have been cold worked to some extent, result in still further increases in strength and, if properly controlled, do not have an adverse effect on the resistance to corrosion. Incorrect aging treatments, hot forming or short-time reheating, however, may considerably reduce the resistance to corrosion.

For most applications, 24S-T or Alclad 24S-T have adequate strength and sufficient workability and are commonly used in this temper. When somewhat greater workability is required, it is common practice to form the material immediately after quenching, but it must be remembered that 24S age hardens rather rapidly at room temperature and retains the higher workability of "as-quenched" material for less than an hour. The better workability can be retained for a considerable time, if desired, by storing the material at about 0°F. immediately after quenching and keeping it at that temperature until the forming is to be done. Hot forming of 24S-T usually is not recommended, since heating the material for as little as 15 minutes at 350°F. to 400°F. markedly lowers the resistance to corrosion. It is possible, however, to form the material hot if the formed part is subsequently aged to one of the artificially-aged tempers (i.e., T81, T86, etc.). This practice has the advantage of minimizing distortion, retaining a good resistance to corrosion and producing a high strength in the finished part. In most cases, severe forming operations are carried out on material in the annealed temper and the formed part then heat treated and quenched, but this practice does have the disadvantage of inducing considerable distortion because of the rapid quench. The use of a less drastic quench minimizes the distortion but markedly reduces the resistance to corrosion of 24S and thin-gauge Alclad 24S. Too slow a quench will result in inferior mechanical properties.

The newest, high-strength alloy, 75S, is as yet available only in the form of extrusions and alclad sheet. Other commodities, undoubtedly, will become available in the near future. This alloy attains a very high tensile and yield strength as the result of solution heat treatment and artificial aging but, in this temper (75S-T or Alclad 75S-T) cannot be formed as readily as 24S-T. The workability of the new alloy in the annealed condition is at least as good as that of 24S-O; in the solution heat-treated condition (75S-W), it can be formed somewhat more easily than 24S-T, if the forming is done within a few days after quenching, and with about the same ease as 24S-T if the forming is delayed for a considerable time. The alloy can be heated for several hours at about 350° F., to permit hot forming, without reducing the strength or resistance to corrosion. The endurance limit of 75S-T is the highest of any of the wrought aluminum alloys.

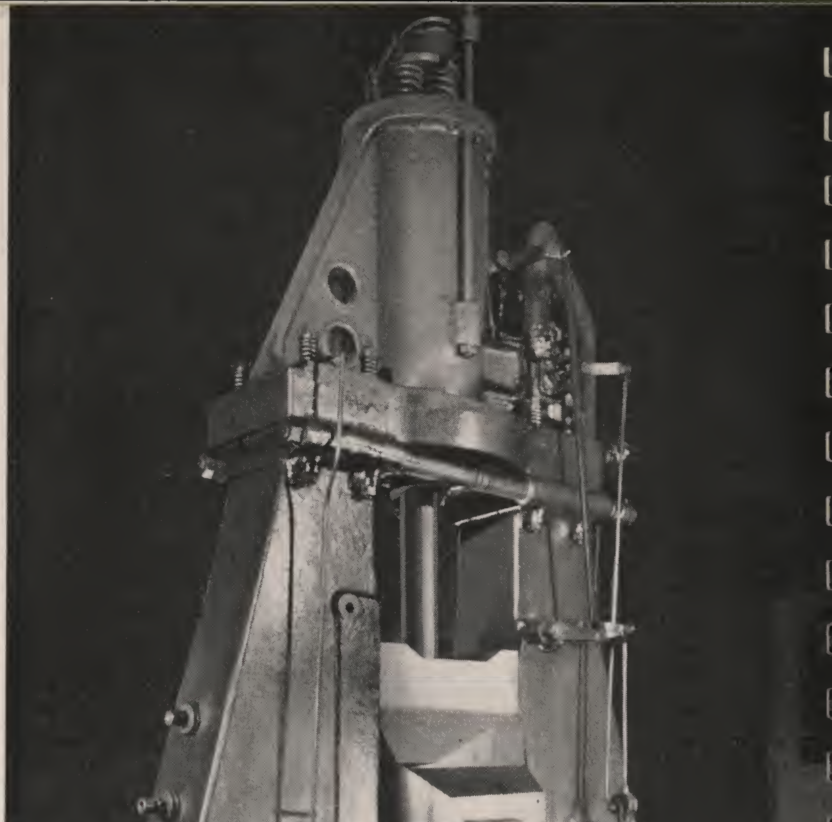
The alloys 53S and 61S both are characterized by moderately high strength, good formability and a high resistance to corrosion. Because of its slightly higher strength and somewhat better formability, the latter alloy is the more widely used and is commercially available in more commodities than the former. Both alloys age harden to some extent at room temperature following the solution heat treatment, but rather severe forming can be accomplished in the "W" temper even after several weeks storage. The maximum strengths are attained by aging the heat-treated materials at an elevated temperature. Since the resistance to corrosion of these alloys is not significantly affected by the temper, rapid quenching is not as important as with 24S and 75S (except as slow quenches may lower the properties) and modified heat treatments, to secure special combinations of properties, can be employed without much thought of their effect on the resistance to corrosion.

The need for an alloy having mechanical properties comparable with those of 17S-T, but with "free-cutting" machining properties, has been filled by the alloy 11S. Automatic screw machine stock is produced in the modified heat treatment, 11S-T3. Experience in a number of plants has shown that the machining quality of this stock is fully equal to that of the free-cutting alloys of other metals which are in common use.

wrought products of aluminum alloys

Aluminum and its alloys are manufactured into all of the forms in which metals are produced, from foil so thin that a pound has a covering area of more than 30,000 square inches, through the range of sheet thicknesses, to plate three inches thick; from wire, one pound of which makes a length of more than 20,000 miles, to rods eight inches in diameter; from angles weighing only four hundredths of a pound per lineal foot, to standard twelve-inch structural channels. Seamless tubes are produced from the size of a hypodermic needle to that required for the mast of an ocean-going ship. These materials, together with castings, forgings, pressings, impact extrusions, rivets and screw machine products, make aluminum readily available for the diversity of uses to which it is put.

The tables at the end of the booklet list the range of commercial sizes of sheet, plate, tubing, bar, rod, wire and shapes. In some cases it may be possible to exceed these limits to take care of specific requirements. Such special cases should be taken up with a sales representative of Aluminum Company of America.



Forging an airplane propeller blade.

alclad products

Alclad is the name given to alloy products the surface of which is aluminum or another aluminum alloy alloyed to and integral with the base metal core.

This name was originally registered by Aluminum Company of America as a trade-mark, but the right of exclusive use has been abandoned in the interest of simplifying the terminology in the aluminum industry.

In most cases, the purpose of the surface layer is to impart superior resistance to corrosion. In order that the composite product shall have the maximum physical properties, the thickness of the surface coating is kept at the minimum which will afford adequate protection. For thick sheet and for plate, the thickness of the surface layers is a smaller percentage of the total thickness than for thinner sheets.

It is noteworthy that the coating not only protects the alloy which it covers, but by electrolytic action prevents attack on the sheared edges of the sheet or other sections of the base alloy which may be exposed by scratches or abrasions. Ordinary alloy rivets, used to join alclad sheet, are likewise afforded considerable protection because of this electrolytic effect. Such protection is accomplished at the expense of some solution of the metal surface layers. Under continued exposure to sea water, corrosion products may accumulate on the surface of the sheet as a result of this action. While the appearance of the metal may be impaired, mechanical test specimens taken from such sheet show that the base metal has not suffered loss of mechanical properties. With proper cleaning the appearance of the surface can be restored without removing the surface metal upon which the protection depends.

Test specimens of alclad sheet, subjected to the standard salt spray test for a period of five years, have shown no loss in mechanical properties. Specimens of 0.032 inch thick alclad sheet have shown no losses after an exposure of 10 years at several outdoor seacoast locations. Except for some solution of the pure metal layer near the machined edges and in a few isolated spots, the sheet appeared bright after both the salt spray and seacoast exposures. A riveted tensile test specimen in which ordinary 17S-T rivets were used to join the alclad sheets, after three years' exposure to three and one-half per cent sea salt spray, had the same strength as the control specimen which had been carefully stored. Riveted panels of 0.064 inch thick Alclad 24S-T sheet with 17S-T rivets had the same strength after four years in the sea at Miami as had duplicate panels which had been stored indoors. Samples taken from the unprotected, 0.0095 inch thick Alclad 17S-T sheet, which formed the skin covering of the dirigible ZMC-2, had the same properties as the original sheet, even after eight years of service.

Although Alclad 24S sheet and plate and Alclad 75S sheet are the only products of this type regularly available today, certain other alclad products can be made available for special purposes. For example, Alclad 3S sheet and tubing are used to some extent for gasoline tanks and for water tanks and lines; the coating alloy, in this product, being one which is particularly adapted for preventing perforation failures.

The use of alclad sheet to replace the plain sheet of the same alloy sometimes requires the use of slightly heavier gauges to compensate for its lower tensile properties. This increased metal thickness does not necessarily represent a corresponding increase in weight of the finished structure, since the weight of the protecting paint film, which is usually applied to the uncoated sheet, may be comparable with the added metal weight.

forgings

Certain of the alloys used for other wrought products are suitable for forging use, while others with more desirable working characteristics have been developed principally for this purpose. The more important of these latter alloys are 14S and 25S. Alloy 14S, although not quite so easily forged as alloy 25S, is quite suitable for most designs. Since forgings of 14S-T have the highest mechanical properties of any of the alloys produced in this form, they find wide application where high strength and good resistance to corrosion are desired.

For some forgings 17S-T is specified because of its greater resistance to severely corrosive conditions. For certain applications, notably in the rayon, dairy and brewing industries, unusually severe corrosive conditions may dictate the use of 53S-T forgings. Architectural hardware is also produced in this latter alloy. Because of its desirable welding characteristics, as well as resistance to corrosion, 2S alloy is occasionally used for press forgings requiring these properties.

Another alloy developed for forging work is A51S. This alloy can be forged even more easily than 25S and is therefore quite suited for large and intricate parts which cannot readily be produced in the harder alloys, provided higher mechanical properties are not required.

For forged parts, such as pistons, in which the retention of strength at elevated temperature is essential, the alloys 32S and 18S are used. In addition to good mechanical properties at the working temperatures of internal combustion engines, 32S has the advantage of a lower coefficient of thermal expansion than that of other wrought aluminum alloys.

A variety of parts can be produced most efficiently as press forgings. In this process, the metal is forced to fill a die cavity by enormous pressures. It differs from the drop-forging process in that steady pressure is used to bring about the metal flow instead of the repeated impacts of the forging hammer. This product can be produced to closer dimensional tolerances than are necessary in the manufacture of die forgings, and hence offers the advantage of requiring less machining for finishing.

impact extrusions

Aluminum and many of its alloys can be fabricated by the impact extrusion process. This process is particularly suited to the manufacture of symmetrically shaped shells having thin walls and a length several times the diameter. The collapsible tube used for the packaging of tooth pastes and cosmetics is a familiar example of this type of product.

extruded shapes

The extrusion process makes possible the production of shapes which have been designed to facilitate the erection of the structure in which they are used, and in which the metal is disposed more efficiently with relation to the stresses which it must withstand than is possible in standard rolled structural shapes. The use of such extruded sections has tended to simplify structural design and has contributed to the economic success of lightweight railway car construction. The saving in erection cost, resulting from the use of special extruded shapes, has gone far in offsetting the higher cost of aluminum alloys as compared with structural steel. Their structural efficiency has made possible even greater saving in weight than could be accomplished by the substitution of standard rolled structural shapes of aluminum alloy for similar sections in structural steel. Their use in architecture makes possible ornamental effects that could not otherwise be obtained.

The choice of alloy depends upon the use that is to be made of the shape. For structural applications, 75S-T affords the highest strength. When the very high strength of 75S is not required, 14S-T shapes can be employed, although this alloy is extruded only in shapes in which the minimum section thickness is one-eighth inch. For thinner sections, 24S-T is used. For many less highly stressed structures 17S is still the standard alloy. For architectural and marine applications 53S is most widely used. The use of 61S is increasing for many purposes for which it is adapted by its good forming qualities, resistance to corrosion and high yield strength. Shapes of 2S and 3S frequently are used where their strengths are adequate and a high resistance to corrosion is required.

screw machine products

Not only bolts, nuts and screws, but a great diversity of parts are made on automatic screw machines. The alloy used in the screw machine stock will vary, depending on the requirements for the finished part. For maximum ease of machining, 11S-T3 alloy rod is used, while for use in aircraft the physical and chemical properties of 24S-T may be required.

heat treatment of wrought aluminum alloys

Heat treatment of aluminum alloys, as the term is commonly used, covers the processes which are used to increase the mechanical properties. The mechanism of heat treatment of aluminum alloys is quite different from that of high-carbon steels. Since there is only one crystalline form of aluminum, there is no question of a change of crystalline form at a critical temperature with consequent recrystallization and change of solubility of the hardening constituent in a different type of crystal. Not all aluminum alloys respond to heat treatment; in fact, this process can be used only with those alloys in which the hardening constituent shows a marked increase in solid solubility as the temperature is increased to temperature just below the melting point of the alloy.

Molten aluminum alloys do not solidify to form a homo-

Propeller blades suspended in rack for heat treatment.

geneous solid of the same composition as the liquid. The first crystals which form have a much lower concentration of the hardening agent than the liquid. Consequently, as freezing continues, the liquid becomes more concentrated and the metal which forms also has an increasing percentage of the hardening agent. When the metal finally solidifies, the last liquid which freezes is so rich in the alloying agent as to form a brittle network between the crystals or grains.

Obviously, the hardening agent is not efficiently distributed in the resulting cast alloy so as to produce the maximum improvement in mechanical properties of the aluminum. Heat treatment offers a means of redistributing the alloying agent uniformly throughout the metal provided the alloy composition is chosen so that all or nearly all of the hardening agent can be put in solid solution at a temperature just below the melting point of the alloy.

The cast alloy is held at a high temperature to bring about partial solution before it is rolled or forged. After the cast structure has been broken down by hot working, further reductions can be made either hot or cold. This working refines the grain structure of the alloy and also increases the ability of the alloying constituents to diffuse and go into solid solution.

Solution heat treatment is, therefore, as the name implies, holding the alloy at a high temperature for a sufficient time to bring about solid solution of the alloying constituent, followed by cooling at a rate so fast as to prevent its reprecipitation in accordance with the lower solubility at room temperatures. Consequently, immediately after quenching, the alloy is substantially a supersaturated solid solution of the hardening agent in aluminum. The strength and hardness are greatly increased over those of the cast alloy or those that result from annealing. The elongation is also higher than that of the cast alloy and about the same as that of the annealed material.

On standing at room temperature, after solution heat treatment, there is a further increase in strength and hardness. The increase in these properties is ascribed to the precipitation from supersaturated solid solution of the hardening constituent so as to produce a particle size more effective in preventing movement within the crystal structure of the metal.

If these alloys are heated at a temperature intermediate between room temperature and the instantaneous annealing temperature, the precipitation takes place more rapidly. In general, the tensile and yield strengths and the hardness increase to values substantially higher than those which are developed by aging at room temperatures. On continued heating, these properties decrease to values below those of room temperature aged material. The elongation decreases to a constant relatively low value, at a rate which is greater, the higher the aging temperature.

By proper choice of the temperature and time of artificial aging, as it is called, it is, therefore, possible to develop higher strengths than those which result from normal aging and still retain sufficient ductility and resistance to shock for structural applications. Simple forming operations can be performed on the material after it has been artificially aged (in the T temper) but more severe working is done after quenching (in the W temper) and the formed part is then artificially aged.

Artificial aging treatments are considerably more effective in increasing the strengths of 24S if the material has been cold worked after the solution heat treatment and before aging; even the small amount of strain hardening introduced by normal flattening operations has a substantial effect. In alloys such as 14S, 53S, 61S and 75S, the effect of cold work following the solution heat treatment is not as marked.

In applying artificial aging treatments to 24S, it is important to recognize the necessity of aging the material for a sufficient period of time to ensure an adequate resistance to corrosion. Short time treatments, although they produce high strengths, very materially lower the resistance to corrosion, but continuing the heating again raises it to substantially the same level as in "as-quenched" material. Artificially-aged Alclad 24S sheet, even if the aging has been for too short a time to secure the best resistance to corrosion, still is superior to "as-quenched" 24S-T except for thin sheet which has been heat treated for an excessive time or has been reheat treated too often.

It should be noted that precipitation heat treatment or artificial aging causes a greater increase in yield strength than in tensile strength. The resulting higher ratio of yield strength to ultimate tensile strength and the lowered elongation may have to be taken into consideration in the design of some structures.

annealing aluminum alloys

The strain hardening, which results from cold working aluminum alloys, may be removed by annealing, i.e., by heating to permit recrystallization to take place. The rate at which recrystallization occurs is greater, the higher the temperature and the more severely the metal has been worked before it is annealed. Complete softening is practically instantaneous for 2S and 52S at temperatures in excess of about 650°F., and for 3S at temperatures of 750°F. or higher. Heating for longer times at somewhat lower temperatures will accomplish similar results. Provided the metal has reached the instantaneous annealing temperature, the exact temperature is not critical, although it is desirable that the recommended values shall not be greatly exceeded and that the metal shall not be held at higher temperatures for excessive lengths of time. The rate of cooling is also not important, although rapid cooling may impair the flatness of the material.

In the case of the heat-treatable alloys, greater care is required in the choice of annealing conditions. The metal must be raised to a temperature which will permit recrystallization in order that the strain hardening shall be removed. On the other hand, the temperature must be maintained as low as possible in order to avoid heat-treatment effects which would prevent complete softening of the alloy, or else the cooling rate must be so slow as to counteract the effect of such heating (see Solution Heat Treatment below).

Heating these alloys to 650°F. is sufficient to remove the strain hardening which results from cold working. This temperature should not be greatly exceeded, nor should the metal temperature in any part of the load be less than 630°F. The rate of cooling from the annealing temperature is not important if the maximum temperature limit has been observed, but slow cooling to a temperature of about 450°F. is a desirable precaution in case any part of the load may have been heated above this temperature.

This annealing practice, in addition to removing the hardening effects of cold working, also removes most of the effects of heat treatment when applied to metal in the heat-treated temper. For many purposes, this practice may be used to anneal the alloys in the heat-treated temper, provided the maximum degree of softness is not required for the forming which is to be done.

For more severe forming, which requires that the metal be in its fully-annealed condition, the following process must be used for metal in the heat-treated temper. The alloy is heated at a temperature of 750°F. to 800°F. for about two hours, and is then allowed to cool slowly in the furnace to a temperature of 500°F. This cooling rate should not exceed 50°F. per hour.

solution heat-treatment practice

The solution heat treatment of aluminum alloys requires control of the temperature within rather close limits and a rapid quench from the heat-treatment temperature. To accomplish the maximum improvement in mechanical properties, the heat-treatment temperature is chosen as high as possible without danger of exceeding the melting point of any constituent of the alloy. If the maximum temperature which is specified is exceeded, there is danger of eutectic melting, with consequent inferior physical properties, and usually a severely blistered surface. If, on the other hand, the metal is heated to a temperature lower than the minimum of the specified temperature range, the physical properties required for the alloy may not be obtained. Prompt transfer of the metal from the furnace to the quench is necessary.

The necessary temperature control is perhaps most readily obtained by means of a bath of fused sodium nitrate. The rapidity with which the metal is brought to temperature is also an advantage of the molten salt bath when alclad sheet is being heat treated, since the shorter the time in the furnace, the less is the tendency for diffusion to occur.

However, air furnaces are also quite satisfactory provided they are designed so as to give the required temperature in all parts of the heating zone. Forced air circulation greatly improves temperature uniformity and increases the rate at which the load is brought to temperature.

When 24S alloy is heat treated in air there is a tendency for the surface to become roughened by minute blisters, and prolonged heating in air may even result in lowered physical properties. This effect is not produced if the alloy is heated in a nitrate bath nor in air furnaces to which a suitable chemical has been added. Alorco Protective Compound placed in air furnaces in small amounts volatilizes and affords complete protection to the alloy. Information concerning the use of this material should be requested by users of 24S alloy who contemplate the use of air furnaces for heat treatment. The use of Alorco Protective Compound is not required for Alclad 24S or for 24S which has previously been given an anodic oxide finish.

Pyrometric control is essential regardless of the type of furnace which is used. Autographic pyrometers should be used, so as to provide a record of the temperature throughout the heating cycle. Automatic pyrometric control of the heating units simplifies the operation of the equipment and is desirable but is not essential if adequate supervision is provided.

The length of time the metal must be held at temperature will vary with the nature of the material. The total time in the heat-treatment furnace will depend, in addition, on the individual equipment which is used and on the size and spacing of the load.

Very short heating periods are sufficient to develop the required mechanical properties when reheat treating 17S-T and 24S-T. However, in order to be certain that maximum resistance to corrosion is also developed, it is desirable when reheat treating these alloys to heat them at the maximum of the recommended heat-treating temperature range and to hold them at temperature at least as long as is done when heat treating 17S-O or 24S-O.

When heat treating alclad sheet, the size of load and spacing should be chosen so as to permit the minimum possible time in the furnace that will develop the required physical properties. Tests should be made with the heat-treating equipment which is used to determine the minimum time required for different thicknesses and classes of product. Prolonged heating causes the alloying constituents of the core to diffuse into the surface layers. Tests made on sheet which had been heated until the copper of the base alloy had diffused through to the surface in spots showed little loss in resistance to corrosion, provided the sheet had been quenched rapidly. However, similar sheets which had been quenched slowly in an air blast were definitely inferior to those which did not show excessive diffusion.

The heat-treating temperatures for the various alloys are shown in Table 3 of the appendix.

For 24S, as well as 17S and A17S, a rapid quench is essential in order that the material shall have the maximum resistance to corrosion. The recommended quenching procedure for these alloys is rapid immersion in cold water. One and one-fourth gallons of water per pound of metal is ample to prevent excessive rise in temperature of the quenching bath when the load is introduced. For products in which the resulting distortion is not too great, high velocity sprays using a large volume of water afford an even more rapid rate of cooling than immersion in cold water.

Milder quenching mediums, such as hot water, oil or air blast may be sufficient to develop the required mechanical properties of the alloy, but the resistance to corrosion of the resulting product is greatly inferior to that of material quenched in cold water.

If a molten salt bath is used for heating the material, all traces of nitrate must be removed by washing the material in warm water (not over 150°F.) after removing from the quenching tank. If the material is to be formed before age hardening takes place, the washing should be done after the forming is completed.

Rapid quenching is recommended in the case of Alclad 24S sheet, also, in order to develop a maximum resistance to attack. However, Alclad 24S sheet which has been quenched in boiling water or certain other relatively slow quenching medium usually is more resistant to corrosion than uncoated 24S which has been heat treated under ideal conditions. Consequently, if it is necessary to heat treat a complicated assembly which cannot be quenched in cold water because of the excessive distortion which would result, the assembly should be made from Alclad 24S sheet rather than from the uncoated alloy. If thin sheet is being used however, the effects of diffusion of copper from the core into the coating of alclad sheet must be guarded against. Slow quenching of thin sheet in which diffusion is excessive will induce as low a resistance to corrosion in this material as it will in 24S. However, insofar as possible, design should be predicated on the use of cold water quenched material.

Lowering a basket of aluminum forgings into a quenching tank, after heat treatment.

The heat treatment of 75S should be carried out according to substantially the same practices as those used for 24S. In fact, sheet of the two alloys can be heat treated in the same furnace loads. Since, however, it is not good practice to heat 75S extrusions to a temperature higher than 880°F., this product should be separated from the other alloys during the heat treatment.

In the case of 53S and 61S, the rate of cooling from the heat-treating temperature has relatively little effect on the resistance to corrosion. Quenching in cold water is the common practice to insure that the required mechanical properties are developed. Where it is desirable, in order to avoid distortion, one of the milder quenching methods may be used.

precipitation heat-treatment practice

The times and temperatures for precipitation heat treatment or artificial aging are shown in Table 3 in the appendix. This operation is carried out in air furnaces or ovens heated by electricity, steam coils or gas. Whichever type of furnace is used, it must be designed to produce uniform temperatures, carefully controlled in all parts of the heating zone. Somewhat more variation in the time of heating is permissible if the lower aging temperature is chosen than is possible with the more rapid aging at higher temperatures. However, if the aging time for any given temperature is too greatly exceeded, the elongation may be reduced below the required value. For this reason, the size and spacing of the load should be such that there is not too great a difference in the time required for different parts of the load to reach the aging temperature. In connection with 75S it should be noted that the aging treatment must be started within 2 hours after quenching or delayed until 24 hours thereafter to secure the best results.

Taking molten aluminum from a holding furnace.

aluminum alloy castings

Alloys of aluminum are used in the production of castings practically to the exclusion of the pure metal, not only because of their higher mechanical properties, but also because of their superior casting qualities.

The elements commonly used in the production of the casting alloys of aluminum are copper, silicon, magnesium, nickel, iron, zinc and manganese, with some use of chromium and titanium. By proper additions from among these elements, the strength of aluminum may be doubled, the elongation usually being reduced and the yield strength and hardness being raised.

Aluminum casting alloys, like the wrought alloys, are of two types: in one, the improved properties result solely from alloying; in the other, heat-treatment processes are used to effect further improvement.

designation

The cast alloys are designated by a number or by a number preceded by a letter to indicate a variation in composition from that of the original alloy; for example, alloy A214 differs from 214 by the addition of zinc to facilitate the pouring of castings in permanent molds.

In the case of heat-treated castings, the heat-treatment condition corresponding to a particular combination of physical properties is designated by the symbol "T" and a number following the alloy number. For example, the alloy of the composition indicated by the number 195 is supplied in several heat-treated conditions, including those designated as 195-T4, 195-T6 and 195-T62.

types of castings

Aluminum alloy castings are poured not only in sand molds, but also in permanent metal molds. In addition certain of the alloys are cast in pressure-die-casting machines, this process also using metal molds or dies.

The type of casting process which is best suited for the production of a given casting depends on a number of considerations. Because of the cost of a permanent-mold or die-casting die in comparison to that of pattern equipment, these processes are practicable only in case a large number of identical castings are required or if savings in finishing costs partially offset the cost of the die. The minimum number which will justify the production of a metal mold or die varies greatly with the nature of the casting.

The surface is generally smoother and the dimensional tolerances closer for castings produced in metal molds than for sand castings. Consequently, the savings in machining or finishing costs may make the permanent mold or die casting more economical than the sand casting in cases where the number required would not otherwise justify the mold or die. For large or intricate cored castings sand molds are necessary.

The mechanical properties of test bars cast in metal molds are, in general, higher than those from the same alloy cast in sand because of the superior metal structure which results from the more rapid rate of solidification. This same superiority in strength is realized in commercial castings, except insofar as problems of mold design may partially offset the advantages of better metal structure.

sand castings

The aluminum sand-casting industry has developed from the use of an alloy containing approximately eight per cent copper, balance aluminum plus the usual impurities. This alloy has been known universally in the foundry trade as "Number 12." Today this older binary alloy has been almost entirely replaced by alloys containing, in addition to the copper, controlled amounts of other elements to improve the casting and machining characteristics.

Alcoa alloys 112 and 212 are of this type and find wide use for general-purpose castings. From the standpoint of mechanical properties there is little to choose between these materials. Alloy 112 has slightly better machining qualities, while alloy 212 has somewhat superior casting characteristics. Except in the case of large production jobs, the difference in machining qualities is probably not sufficient in itself to determine the choice.

Alloys containing silicon as the hardener have excellent casting qualities and can be used in the production of large thin-sectioned castings which are intricate in design, or of castings which have adjoining heavy and light sections; they are also employed in the production of castings which must withstand fluid pressures without leaking. In addition, the aluminum-silicon alloys have excellent resistance to corrosion. Certain compositions are susceptible to heat treatment or to special foundry practices (modification) to improve their mechanical properties.

Alcoa alloy 43, containing five per cent silicon, is widely used in this country. Its tensile and yield strengths are somewhat lower than those of the aluminum-copper alloys (112, 212), but it is appreciably more ductile and resistant to shock. Because of its excellent casting qualities and resistance to atmospheric attack, it is used practically to the exclusion of other alloys in the production of architectural and ornamental castings. Marine castings are also made of it because of its satisfactory performance in salt-laden atmospheres.

Alloy 47 contains 12.5 per cent silicon. When cast without the use of special casting practices the alloy is quite brittle and has a coarse crystalline fracture. By the use of the "modification" process, sand castings can be produced having distinctly higher strengths than those of 43 alloy, and higher elongation as well. The fracture of the "modified" or the chill-cast alloy is fine-grained, and is commonly designated as "silky."

Alloys containing magnesium in suitable proportions are even more resistant to corrosion than the aluminum-silicon alloys. Alloy 214, for example, containing 3.8 per cent of magnesium, has higher mechanical properties than alloy 43 and is more resistant to corrosion, except in acid solutions, but is not so readily cast into intricate leakproof castings. It is employed in the production of castings for use in sewage disposal plants, chemical plants and dairy equipment; it is also used in cast cooking utensils and for the production of marine castings.

For certain special applications, other compositions may be recommended. Alloy 108 contains both silicon and copper and combines some of the desirable characteristics of these two classes of alloys.

Alloy A334 has mechanical properties slightly better than those of 112 and 212 alloys, as well as somewhat superior casting properties. It can be used for the production of castings of intricate design, in which pressure tightness is required. It may be subjected to an artificial aging treatment to increase its hardness and to improve its machining qualities.

Zinc is sometimes used as a hardener for aluminum; in fact one alloy commonly used in Europe contains zinc and copper as the major alloying elements. Alloys of this type, although they develop quite interesting mechanical properties after casting, age rapidly at room temperature with a substantial reduction in ductility. For certain applications, however, such alloys are used quite satisfactorily. Alcoa alloy 645 is a material of this type providing mechanical properties intermediate between those of the common aluminum-copper and aluminum-silicon alloys and the heat-treatable alloys.

heat-treated sand castings

The use of heat-treated castings, having properties greatly superior to those which have just been considered, has increased greatly during the years since they were first introduced by Aluminum Company of America.

The alloy in greatest use is the one from which heat-treated sand castings were first produced. It is known as alloy 195 and contains about four per cent copper. Castings are produced in several heat-treated conditions, that produced by solution heat treatment followed by room-temperature aging (195-T4) being the one most commonly used. Precipitation heat treatment following the solution heat treatment produces 195-T6 and 195-T62, having higher tensile and yield strengths but lower elongations than 195-T4. On aging at room temperature for several months, the mechanical properties of the alloy in the latter temper approach those of 195-T6, after which there is no further appreciable change.

Alloy 356, containing silicon and a small amount of magnesium, is also produced in several heat-treated conditions. This alloy, in common with the other aluminum-silicon alloys which have been described, has excellent casting qualities and resistance to corrosion. It is used mainly for the production of castings in which superior mechanical properties are required, but which cannot be produced economically in 195 alloy because of its foundry limitations.

The tensile properties of 356 alloy in the different heat-treated conditions vary in the same manner as the corresponding tempers of 195 alloy, and are only slightly lower than

Aluminum permanent-mold and semi-permanent-mold castings.

those of the latter alloy. Castings in 356 alloy are less resistant to shock and impact loads than those in 195 alloy, but are more resistant to severely corrosive conditions of exposure.

Castings in alloy 220-T4 have the highest combination of tensile and yield strength, elongation and resistance to impact of any of the aluminum alloy castings. This alloy also has excellent machining qualities and resistance to corrosion. The characteristics of the alloy are, however, such as to make it unsuited for castings required to be pressure tight or castings which are subject to use at elevated temperatures. The alloy ages somewhat at room temperature although to a less degree than 195-T4 alloy. The high magnesium content makes necessary the use of special foundry practices.

The alloys 122, 142, 355 and A355 all possess the quality of retaining in relatively large measure their strength and hardness at elevated temperatures such as those which prevail in internal-combustion engines. All are susceptible to improvement by a variety of heat-treatment operations. The choice of both alloy and temper depends on the service conditions to be withstood by the casting.

Alloy 122 finds its greatest use in automotive pistons, and hence is largely confined to permanent-mold production. In sand it is used principally for pump cylinder housings and other applications requiring good wearing characteristics. Alloy 142 is also used for similar applications, but its greatest use is for cylinder heads for air-cooled aircraft engines, requiring good retention of mechanical properties up to temperatures of 500°F. to 600°F. Alloy 355 and the modified composition A355 alloy are especially suited for the production of crank cases and cylinder heads and similar castings for the manufacture of liquid-cooled aircraft engines and for Diesel engines. The latter alloy is used in case operating temperatures somewhat in excess of 400°F. may be encountered.

The relations between the different heat-treated conditions are similar to those which have been discussed for 195 and

356 alloys. In addition, these alloys may be subjected to heat treatments having for their primary purpose the stabilization of dimensions against change when maintained at elevated temperatures.

In Table 10 will be found a list of the alloys commonly used in the production of sand castings together with their physical properties. Other alloys designed for special applications are also available on request.

permanent-mold castings

Castings made in metal molds may be of two types, the full permanent type which is made in a metal mold with metal cores, and the semi-permanent type which is made in a metal mold with sand cores. The use of sand cores removes many of the production limitations imposed by metal cores and greatly expands the use of the permanent-mold process. Because of the finer grain structures resulting from the rapid solidification of the metal in permanent molds, castings so produced possess certain metallurgical and mechanical property superiority to castings produced in sand molds.

The selection of an alloy for a permanent-mold casting depends both on the nature of the casting and the service it is to perform. This question can best be decided by consultation with a sales representative of Aluminum Company of America who is familiar with the production and the properties of permanent-mold castings. Where this process is applicable, it offers not only the mechanical advantages which have been mentioned, but also closer dimensional tolerances. Finishing costs may be materially lower than those for sand castings as a result of the saving in machining.

Some of the alloys used in making sand castings are also poured in permanent molds, while others have been developed primarily for this purpose. The composition and physical properties of some of the most commonly used permanent-mold alloys are listed in Tables 7 and 10.

As in the case of sand castings, alloys containing approximately eight per cent copper are widely used for general-purpose castings produced in permanent molds. Two such alloys, B113 and C113, have been developed particularly for this purpose. Both alloys possess casting qualities and mechanical properties quite satisfactory for many applications.

Alloys 122, A132 and 142 are commonly known as piston alloys, being used principally for the production of internal-combustion engine pistons. Of these, A132, or Lo-Ex* alloy as it is called by the trade, finds most favor, because it has the lowest coefficient of thermal expansion of all the commercial alloys of aluminum. All these alloys possess good wearing characteristics and the quality of retaining their strength well at elevated temperatures such as encountered in internal-combustion engines. They are also susceptible to heat treatments for improvement of their physical properties and stabilization of dimensions against undesirable changes during operation at elevated temperatures.

Alloy A108, containing both copper and silicon, and combining some of the desirable characteristics of both classes of alloys, possesses good casting properties for the more intricate permanent-mold castings.

Alloy 138 has excellent hardness in the cast condition, which is retained well at elevated temperatures. It is used for parts such as flatiron soleplates, which require maximum hardness at operating temperature.

Alloy A214 is a modification of the sand-casting alloy 214, developed because of its superior qualities for casting in permanent molds. Its tarnish resistance is substantially the same as that of the sand-casting alloy from which it was developed. It is especially desirable for the production of cast cooking utensils.

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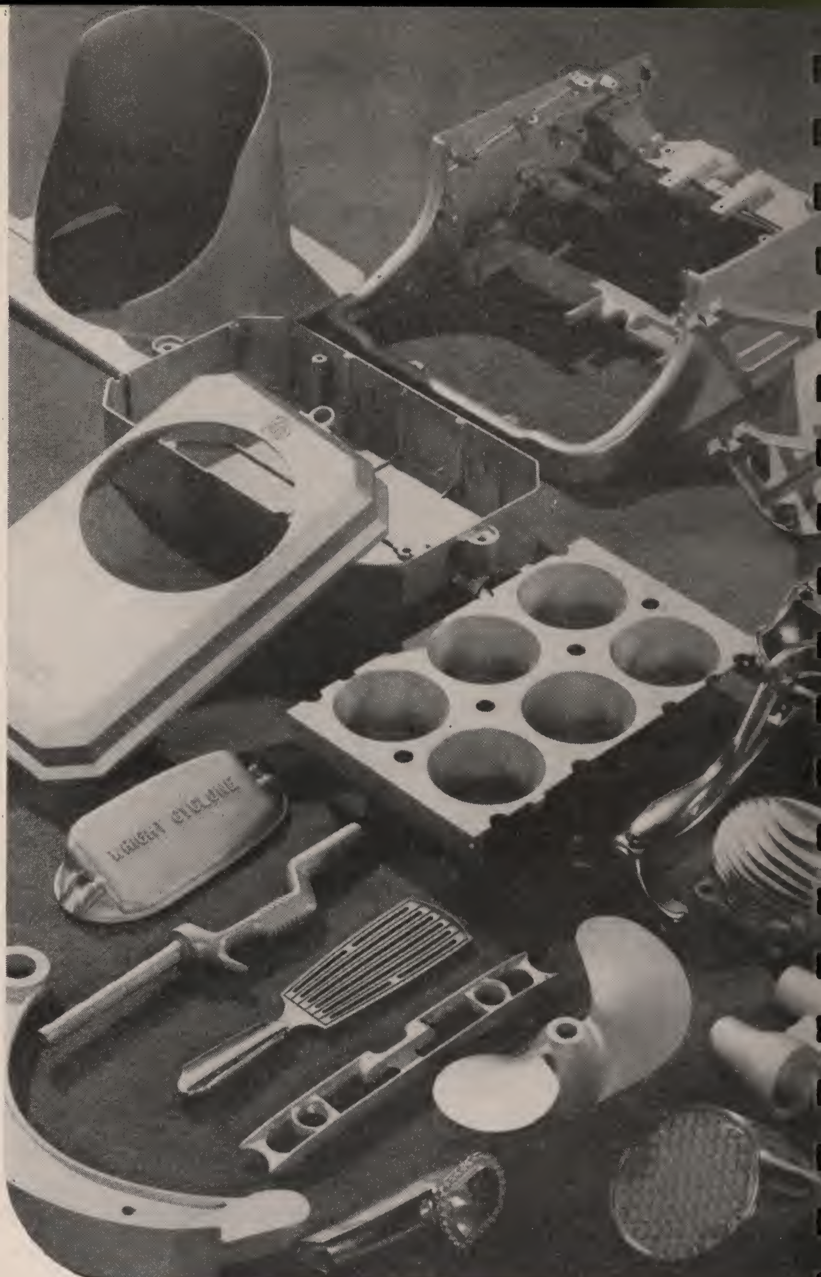


Aluminum die castings.

Alloy 195 is not suited for production in permanent molds, but a modified composition (B195) is widely used. Castings in this alloy poured in permanent molds have appreciably higher tensile and yield strengths after solution heat treatment (B195-T4) than those of sand-cast 195-T4.

Alloys 355 and 356 are used in permanent molds without any modification of the compositions which are used for sand castings. In this case, also, the improved metal structure resulting from the more rapid solidification permits higher tensile properties to be developed by heat treatment than when cast in sand. These alloys have the same applications as in sand castings, 356 being particularly desirable for castings requiring high resistance to corrosion.

die castings

Die castings of aluminum alloys possess the qualities of light weight, resistance to corrosion and permanence of dimensions. Because of these properties, in addition to those inherent in the die-casting process, namely, accuracy of dimensions and good surface finish, aluminum alloy die castings have found steadily increasing use since the time when improvements in die steels made possible the use of this process with aluminum.

Several aluminum alloys are used for the production of die castings; those used by Aluminum Company of America are shown in Table 15. Questions involving the possibility or advantages of using aluminum alloy die castings as well as the most suitable alloy for any application should be discussed with the die-casting specialist.

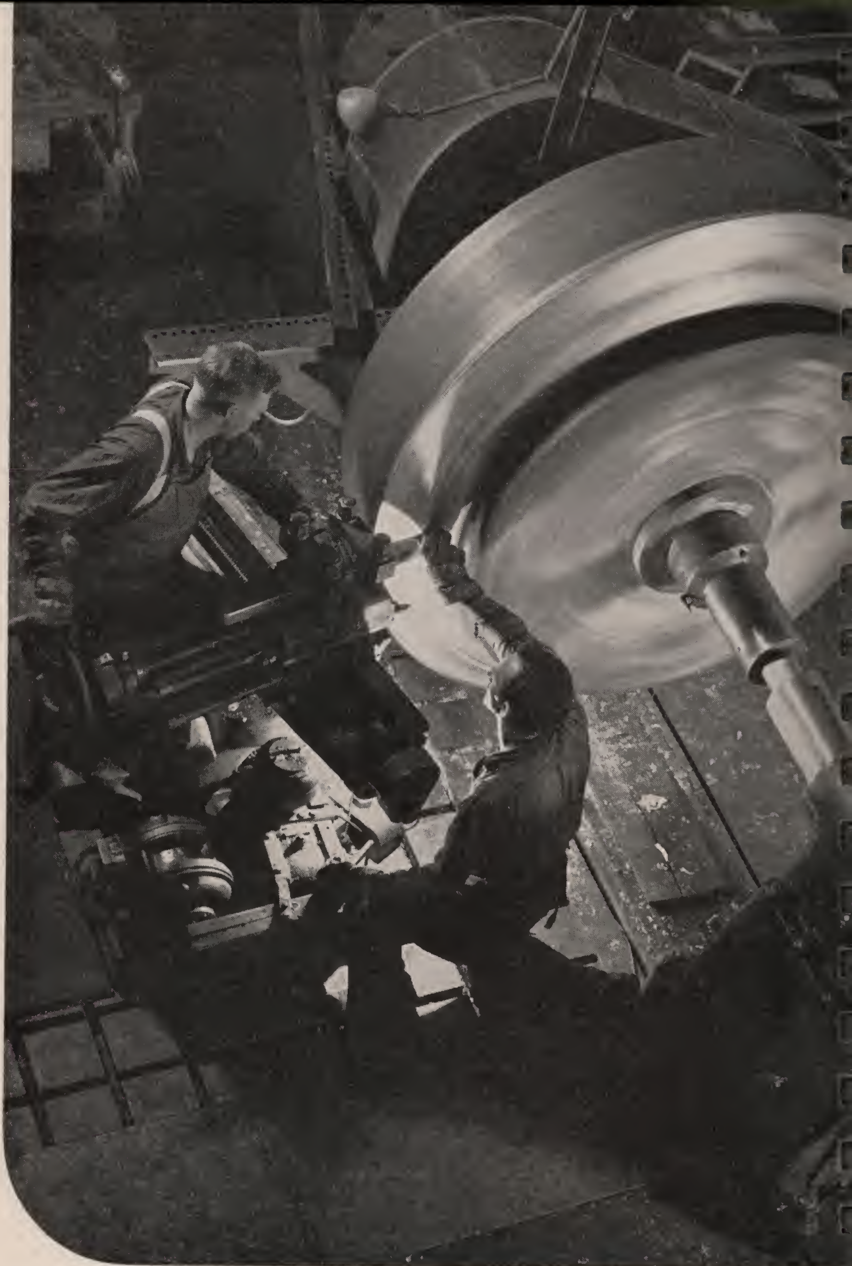
design of aluminum alloy castings

The mechanical properties of the various alloys referred to in the foregoing section and contained in the tables are values obtained from standard A.S.T.M. ½-inch diameter test specimens separately cast and tested without machining the gauge section. These test specimens are cast under conditions which duplicate as closely as possible the conditions of solidification of the casting. When cast under such standard conditions, these test specimens serve as a control of the metal quality, and in the case of heat-treated alloys, they also serve as a control of the heat-treating process, since they must be heat treated with the castings they represent.

The properties of separately cast test specimens do not necessarily represent the properties of commercial castings, and may be either higher or lower, depending on a number of factors which influence the rate of solidification of the metal from the molten state. For the same reasons, the properties of test specimens machined from castings will vary, depending on the location from which they are taken. Such foundry considerations as section thickness, gating and risering, chilling, pouring temperature, permeability and moisture content of sand, and any other factors which influence the rate of metal solidification have a material effect on the mechanical properties of the resulting casting.

These relations are not peculiar to aluminum alloy castings but exist in castings of all metals. They introduce two specific problems for the designer of cast metal parts: first, the selection of the proper alloy considering such factors as foundry characteristics and physical properties; and second, the selection of the proper factor to apply to the properties specified for an alloy in determining the design stress. Such factors must take into account the type of service in which a casting will be used, as well as the variation in the properties of the sections of each commercial casting. There is no known "rule of thumb" from which these factors can be determined, and in fact most designers develop their particular method from experience with specific metals and types of castings. The properties of test specimens machined from the specific casting being designed, and proof load or breakdown tests on the casting, assuming service loading conditions, provide data which are extremely useful in this connection if either the design or application of the casting is new. The latter method, particularly, is finding favor as a means of checking the design of aluminum alloy castings.

The services of the engineering and technical staffs of Aluminum Company of America are available on request to assist in the selection of alloys for casting applications as well as in the designing of cast parts.



Machine-spinning a large aluminum container.

fabricating practices

WITHIN the scope of this booklet it is possible to treat only in a general way the various fabricating processes to which aluminum may be subjected. It may be stated that aluminum alloys are being formed and fabricated into the most diversified types of assemblies in plants and shops in all parts of the country, using the same types of equipment and personnel as are used in handling other metals. There are certain differences in the working characteristics of aluminum which should be observed to obtain best results, and these will be briefly considered. For more complete information the following booklets have been prepared and are available on request to the nearest sales office of Aluminum Company of America:

Machining Alcoa Aluminum
Welding and Brazing Alcoa Aluminum
Riveting Alcoa Aluminum
Aluminum Casting Alloys
Finishes for Aluminum
Aluminum Paint Manual

forming

Commercially pure aluminum (2S) is outstanding for the ease with which it can be drawn, spun, stamped or forged. Starting with the metal in its annealed temper, articles requiring several successive drawing and spinning operations may be made without the necessity of any intermediate annealing. Since the alloys are less ductile than the pure metal, they require more liberal radii for bends and are capable of withstanding less severe forming. However, there is a range of fabricating qualities among the various alloys in their different tempers, from 3S-O, which is only slightly less ductile than 2S-O, to 24S-RT which is used only where the amount of forming is limited to bending over rather liberal radii.

The alloys 2S, 3S and 52S cover a wide range of mechanical properties in their various tempers. Since their harder tempers are obtained by cold working during the process of manufacture, the amount of forming which can be done on them is greater, the softer the temper. For many drawing operations, the half-hard temper retains sufficient ductility for good working qualities even in 52S, and some less severe draws are successfully accomplished with this alloy in the hard temper.

The forming qualities of 53S and 61S in the annealed temper are very similar to those of 2S-O and 3S-O; in the heat-treated and the heat-treated and aged tempers, these alloys form more nearly like 2S in the harder tempers. The most severe forming operations, therefore, should be carried out in the annealed temper and the material then heat treated and aged. For those operations which cannot be completed successfully in the fully-aged (T) condition, but for which the high degree of workability of annealed material is not required, the use of the W temper is recommended. The formed part can then be aged to the maximum strength. Of the two alloys, 61S has the better workability despite the fact that its yield strength is comparatively high.

A considerable amount of forming can be accomplished with 24S-T even though the workability of this material is not as high as that of most other aluminum alloys. More severe operations, requiring sharper bends or a substantial depth of drawing, may have to be performed on the annealed alloy and the formed article subsequently heat treated. In many cases, the forming is done immediately after the material has been quenched. Age hardening then takes place in the finished part, thus avoiding the possibility of distortion or warping during heat treatment and the consequent necessity for straightening.

In drawing or stamping operations, successful results may depend on the choice of the proper lubricant. The light lubricating oils, marketed under the designation "metal oil," are most commonly used in large scale operations. The best lubricant is tallow, mixed with a small amount of mineral oil, but because of its greater cost and the greater difficulty of applying it to the blank and removing it from the finished work, it is used only on more difficult operations for which metal oil does not prove successful.

The surface finish of the tool also exerts considerable influence on the results. Tool steel with polished surfaces may be required for more difficult draws of the harder alloys, while for many jobs, cast steel or even cast-iron tools are satisfactory, provided the number of parts which are to be made is not too great.

In forming aluminum alloys it is necessary to recognize their characteristic properties. The chief requirement for successful working is that the tools shall permit a suitable radius for bending and drawing operations. The radius which is required varies both with the grade of the alloy and with the thickness of the material. The radius of a bend will also depend to some extent on the type of bending equipment which is used. Frequently, a small change in the tools has been found sufficient to obviate the necessity of choosing a soft temper or a softer alloy. In some cases, this change consisted only in the slight rounding of a sharp edge or merely a polishing operation to improve the surface so as to prevent the metal from flowing into scratches or flaws in the tools, which action would cause the metal to tear. In certain difficult forming operations, it may be necessary to resort to successive draws with inter-

Electric seam welding an aircraft part.

mediate annealing, starting, of course, with annealed material.

Table 2 is intended as a guide in the choice of a suitable material or of a proper forming radius, not as a tabulation of definite operating limits. The final choice of the alloy or of the working radius should be based on a trial under the conditions to be used in production. The relative ease of forming is also affected by the nature of the forming process. While experience in handling these alloys makes possible some prediction as to the material which may be used, the final answer must be obtained by actual trial of different materials on the production tools.

hot forming

In common with most other metals, the forming properties of the aluminum alloys are improved by heating the material to suitable elevated temperatures. Most of the alloys can be heated to about 400°F. for about half an hour in order to carry out hot forming operations without any harmful effect on the mechanical properties. Heating to temperatures much in excess of this may result in partial or complete annealing of strain-hardened or heat-treated materials and is quite apt to adversely affect the resistance to corrosion of 17S-T and 24S-T. In heavy sections, this latter effect of heating may not be a serious matter, but that it may occur should be kept in mind. Hot forming does not affect the resistance to corrosion of 53S-T and 61S-T.

Since hot forming of the heat-treatable alloys can be carried out at temperatures suitable for artificial aging, it often is possible to form 14S-W, 24S-T, 53S-W, 61S-W and 75S-W at elevated temperatures and then age the formed article to its maximum strength by reducing somewhat the usual aging time, to compensate for the aging which has taken place during hot forming. This practice is especially useful for the thinner sections of 24S-T, which suffer the most from reheating.

Torch welding aluminum.

Heat-treatable alloy plate can be formed into angles and other shapes by heating the metal and forming it in dies. For some classes of material, the best working temperature is in the heat-treatment range. In these cases, the chilling of the metal in the steel dies may constitute a satisfactory quench, such that the mechanical properties of the heat-treated temper will be developed in the finished part after a suitable aging. In some cases, the metal must be formed at a temperature lower than that required for heat treatment. Where this applies, the advantage of quenching in the dies to avoid warping may be obtained by reheating the formed section to the heat-treating temperature and replacing it in the dies instead of quenching in water. Natural aging or precipitation heat treatment, as may be appropriate for the alloy, will then develop the full properties of the metal. It must be emphasized that die quenching can be relied on to give satisfactory results only in case the die is of such a character that there is intimate contact with the metal which is being formed. The dies must also be of sufficient mass to absorb the heat from the alloy and bring it promptly to room temperature.

welding

The aluminum alloys are joined by welding as a common commercial practice. Torch, arc or resistance welding are applied as the parts may require. The technique of welding aluminum differs from that used on steel, but is readily mastered with a little practice.

Because of the oxide film which forms on an exposed surface, it is necessary to use a flux in torch or arc welding aluminum. For arc welding, a flux-coated rod is used to advantage. When welding the nonheat-treatable wrought alloys by either of these processes, a welding rod of 2S or of the same composition as the alloy which is being welded is often used, although an aluminum alloy rod containing five per cent of silicon is more readily handled and gives better results in complicated welds. This latter rod is recommended for most applications in the welding of the heat-treatable wrought alloys. For castings the rod is commonly the same alloy as the casting.

Butt, lap and fillet joints are made by torch welding, using either the oxyhydrogen or the oxyacetylene flame, with comparable facility to similar joints in steel.

There are some limitations to the applications of arc welding; however, butt joints are readily made on material thicker than about 5/64 inch. This process has the advantages of greater speed and less distortion of the part as compared with torch welding; also, the effect on the structure and temper of the parent metal extends a smaller distance from the joint.

Some general considerations should be taken into account in designing parts containing welded joints. The strain-hardened alloys after welding are annealed for a short distance from the weld. The metal in the weld has a cast structure having about the same strength as the annealed metal, but less ductility. If the weld bead is left as welded, the joint is usually stronger than the adjacent metal. Grinding of the welds, however, will reduce the strength of the joint somewhat; but hammering them will generally accomplish the same purpose as grinding, without the sacrifice in strength.

Welding the heat-treated alloys tends to destroy the effects of prior heat treatment. The annealing temperature range is exceeded in the metal adjacent to the weld, but the rate of cooling in the air is fairly rapid; consequently, its strength is usually intermediate between that of the fully-annealed alloy and that which would result from the solution heat treatment. The change in the temper of the metal resulting from the heating also has an adverse effect upon its resistance to corrosion. The loss in these properties can be partially recovered by reheat treatment or by performing the welding operations before heat treatment where this plan is feasible. Where the joint is depended on for maximum efficiency, torch welding, and in many cases arc welding, cannot be considered equal to a well-designed mechanical type of joint.

Resistance Welding: Resistance welding (embracing spot, seam and butt welding) may be employed in the fabrication of aluminum in a manner similar to that used for other materials. Because of the entirely different physical characteristics of aluminum, the technique and equipment employed will differ considerably from that used for steel. In some cases, however, equipment used for steel may be modified or added to, in order to provide excellent results when used with aluminum or its alloys.

In addition to the required changes in equipment, several times the electrical capacity is required for aluminum as compared with a similar resistance weld application in steel. Because of the special requirements in technique and equipment involved, advice with reference to the resistance welding of Alcoa Alloys is available on application to the nearest sales office of Aluminum Company of America.

brazing

A new joining process termed "brazing" has found production application on some of the aluminum alloys. The process differs from welding in that only sufficient heat is applied to flow filler material into the joint with little or no melting in the parent part. The brazing heat may be applied to a batch of parts in a furnace, or by dipping in molten flux or with a torch in a manner resembling torch welding.

Brazing offers several advantages over torch and arc welding: it can be applied to thinner material, costs are lower, and surface appearance is usually better. Since the brazing metals are all aluminum alloys, the difference in electrolytic potential between the joint and the main body of the work is relatively

Furnace brazing gasoline tanks for outboard motors.

small. Service experience over the months that the process has been in use indicates good resistance to corrosion, more nearly comparable to that of welded, than of soldered, joints. In strength the joint is strictly comparable to a welded joint.

Brazing techniques for handling alloys 2S, 3S and 61S have been developed. Special fluxes and filler materials are stocked for distribution. Detailed information can be obtained on application to the nearest sales office of Aluminum Company of America.

machining

Aluminum alloys, both cast and wrought, are readily machined; it is necessary only to observe certain differences in practices from those generally used with other metals. The choice between plain high-carbon tool steel and high-speed steels is governed by the same production considerations as with other metals. Cemented tungsten carbide tipped tools offer distinct advantages and are required for best results with the aluminum alloys of high silicon content.

In general, tools for machining aluminum should have appreciably more side and top rake than are required for cutting steel; in fact, their shapes approximate more closely those used with hard woods. In addition, the edges should be keen and smooth, a result which is accomplished by finishing on a fine abrasive wheel followed by handstoning or lapping.

Lathe tools are set considerably higher on the work than is general practice with steel. Twist drills with large spiral angles are usually to be preferred. In selecting saws and files the same principles should be considered as have been mentioned for machining tools.

In general, best results are obtained using comparatively high speeds and fine to medium feeds; the finer the feed, the higher the speed. The use of a lubricant is quite desirable and it should be used copiously. For general use, a mixture of kerosene and lard oil is quite satisfactory as a cutting compound, and for milling, sawing and drilling, the more economical soluble cutting oils may be used.

riveting

Riveting is the most commonly used method of joining aluminum alloys, especially the heat-treatable alloys which depend on carefully controlled thermal treatment to develop their characteristic mechanical properties and consequently cannot be welded without sacrifice in strength (see Welding, page 77).

The choice of material in the rivet depends on a number of considerations. For use with 2S and 3S, rivets of 2S alloy are usually chosen; for 52S, rivets of 53S are used. Rivets of 53S-T can be driven cold, although for the larger sizes, 53S-W or 53S-T61 may be preferred because of the greater ease of driving. For use with alclad sheet, 53S rivets are recommended because of their excellent resistance to corrosion and the fact that they have practically the same solution potential as the surface metal of the alclad sheet.

Either A17S-T or 17S rivets are commonly used with 17S-T and 24S-T. The use of A17S-T rivets has the advantage that they can be driven more easily in the condition as received from the manufacturer, while 17S rivets are usually reheat treated and driven before the age hardening has taken place.

For some structures the use of larger rivets than can be driven cold in 17S alloy is required. Under some circumstances it may be more convenient to use hot steel rivets, provided the assembly can be thoroughly painted. The alternative is to drive 17S rivets hot, that is, from their heat-treatment temperature, depending on the contact with the heading tools and the surrounding metal for the quench to develop the properties of 17S-T.

painting aluminum alloys for protection

The use of paints on aluminum alloys may be found desirable for decoration or, in some cases, necessary for protection. Adequate preparation of the surface and careful selection of the paints are important if lasting service is to be secured. For most applications a treatment in a dilute aqueous solution of phosphoric acid gives adequate surface preparation; these solutions should contain organic grease solvents in addition to the phosphoric acid. Solvent cleaning is less effective than the phosphoric acid treatment but under some conditions may be employed. For more severe service conditions, such as on parts constantly wet or subjected to high humidity, the use of either anodic coatings or Alrok* oxide coatings is advantageous in promoting the adhesion of the paint and in increasing the protection of the alloy.

Priming paints containing a substantial quantity of zinc chromate pigment have been found to be the most effective primers for use on aluminum, particularly under conditions of severe exposure. In many cases, however, aluminum paint. made by mixing aluminum paste with a suitable varnish vehicle, constitutes a satisfactory primer. Special primers must be used if lacquer finishing coats are to be applied. Aluminum paint is especially recommended for finishing coats, where its color is satisfactory, because of its properties of great opacity and high impermeability to moisture. However, any finishing paint, satisfactory for use on other metal surfaces, may be used. Bituminous paints may be advantageously employed where the alloys are to be in contact with alkali-containing materials such as mortar or in damp environments away from sunlight.

***Registered trade-mark—Aluminum Company of America.**

tables

Many of the alloys included in this booklet, their processes of fabrication or casting, their heat treatment, or the products of one or more of these operations are covered by United States patents.

INDEX TO TABLES

Table	general information	Page
	Definitions and significance of terms used in tables	88
1	Standard commodities—wrought alloys	89
2	Approximate radii for 90° cold bend of sheet	90
3	Conditions for heat treatment	91
4	Approximate tempers of rolled and cold-finished bar and rod	92
	chemical composition	
5	Wrought alloys	93
6	Sand-casting alloys	93
7	Permanent-mold casting alloys	94
8	Die-casting alloys	94
	general properties	
9	Wrought alloys	95
10	Sand-casting alloys	96
11	Average coefficients of thermal expansion	98
	mechanical properties	
12	Wrought alloys	99
13	Sand-casting alloys	100
14	Permanent-mold casting alloys	103
15	Die-casting alloys	106
16	Alloys at elevated temperatures	107
	specified mechanical properties	
17	Sheet and plate—2S, 3S and 52S	110
18	Forgings	111
19	Bar and rod—11S alloy	111
20	Products of 17S alloy	112
21	Products of 14S alloy	113
22	Products of 24S alloy	114
23	Products of 53S alloy	116
24	Products of 75S alloy	117
25	Products of 61S alloy	118
	commercial tolerances	
26	Sheet and plate—thickness	119
27	Sheet and plate—width, length and diameter	121
28	Rolled structural shapes	122
29	Wire, rod and bar	123
30	Rough-rolled, round-cornered squares and rectangles	124
31	Flattened, and flattened and slit wire	124
32	Extruded rods, bars and shapes	125
33	Drawn tubing	128
34	Extruded tubing	130

standard sizes

Table *Page*

35 Flat sheet and plate—Alcoa standard sizes.................. 133

commercial sizes

36 Flat sheet—2S and 3S................................ 135
37 Coiled sheet—2S and 3S.............................. 136
38 Flat sheet—52S...................................... 137
39 Coiled sheet—52S.................................... 137
40 Flat sheet—61S (O, W and T tempers)................. 138
41 Flat sheet—24S and Alclad 24S (O and T tempers)........... 138
42 Flat sheet—24S-RT and Alclad 24S-RT.................. 139
43 Alclad 14S, 75S and Alclad 75S Alloy Flat Sheet (O and T tempers) 139
44 Coiled sheet—24S, Alclad 24S, 75S and Alclad 75S (O and T tempers) and Alclad 14S and 61S (O, W and T tempers)................................. 139
45 Plate—2S and 3S..................................... 140
46 Plate—52S... 142
47 Plate—24S and 61S................................... 144
48 Maximum commercial sizes of heat-treatable alloy plate Alclad 14S, 75S and Alclad 75S............................. 146
49 Tubing—Alcoa standard sizes......................... 148
50 Alcoa tread plate—61S............................... 148
51 Structural shapes................................... 149
52 Round tubing.. 150
53 Wire, rod and bar—all alloys........................ 152
54 Rough-rolled, round-cornered squares and rectangles—all alloys 153
55 Flattened, and flattened and slit wire.................. 153

DEFINITIONS AND SIGNIFICANCE OF TERMS USED IN TABLES

1. For all Alcoa alloys, wrought and cast, the following approximate data apply:

   (a) Modulus of Elasticity........................10,300,000 lb./sq. in.[1]

   (b) Modulus of Rigidity.......................... 3,850,000 lb./sq. in.

   (c) Poisson's Ratio.............................. 0.33

2. Yield strength is the stress which produces a permanent set of 0.2 per cent of the initial gauge length (American Society for Testing Materials Standard Methods of Tension Testing—E8-42).

3. Endurance limits are based on 500,000,000 cycles of completely reversed stress using the R. R. Moore type of machine and specimen.

4. Elongation varies with the form and size of test specimen. When round specimens are used the gauge length for the measurement of elongation is equal to four times the diameter of the reduced section of the specimen.

5. Dimensions given in tables for the following products are as listed below.

Sheet and Plate:	Thickness
Tubing:	Outside diameter
Forgings:	Diameter or thickness
Wire, Rod and Bar:	Diameter or least distance between parallel surfaces, or where so stated maximum area of cross section. Maximum size of hexagon is 3 inches; of octagon, 1 3/16 inches; of square, 4 inches.

[1]The modulus varies somewhat with the alloy. Some specific values are as follows:

2S, 3S, 53S and 61S	10,000,000 lb./sq. in.
11S, A51S, 52S	10,200,000 lb./sq. in.
17S, 25S, 75S, 76S	10,400,000 lb./sq. in.
14S, 24S	10,600,000 lb./sq. in.
18S	10,800,000 lb./sq. in.
32S	11,400,000 lb./sq. in.

TABLE 1

Standard Commodities[1]—Wrought Alloys

(Commodities marked * are standard.)

Alloy	Sheet	Plate	Wire	Rod	Bar	Rolled Shapes	Extruded Shapes	Drawn Tubing and Pipe [5]	Rivets	Forgings
2S	*	*	*	*	*	....	....	....	*	[4]
3S	*	*	*	*	*	....	*	*	....	....
Alcad 3S	...	...	...	...	...	....	....	[6]	....	....
11S	...	...	*	*	[3]	....	....	....	....	....
14S	...	...	...	...	...	*	*	....	....	*
Alcad 14S	*	*	...	...	...	....	....	....	....	....
17S	...	...	*	*	*	....	....	....	*	*
A17S	...	...	[2]	...	...	....	....	....	*	....
18S	...	...	...	...	...	....	....	....	....	*
24S	*	*	*	*	*	....	*	*	*	....
Alclad 24S	*	*	...	...	...	....	....	....	....	....
25S	...	...	...	...	...	....	....	....	....	*
32S	...	...	...	...	...	....	....	....	....	*
A51S	...	...	...	...	...	....	....	....	....	*
52S	*	*	*	*	*	....	....	*	....	....
53S	...	...	[2]	*	...	*	....	....	*	*
56S	...	...	*	...	...	....	....	....	*	....
61S	*	*	*	*	*	*	*	*	....	....
63S	...	...	...	...	...	....	*	....	....	....
75S	*	*	*	*	*	....	*	....	....	....
Alclad 75S	*	*	...	...	...	....	....	....	....	....

1 Commodities marked * are produced in routine commercial production. Sales representatives of Aluminum Company of America should be consulted concerning the possibility of obtaining other commodities in the various alloys. For list of sales offices see page 168.

2 Rivet wire only is a standard product; other sizes and tempers are not regularly produced.

3 Available in hexagons only.

4 Standard for press forgings only.

5 For extruded tubing, use column for extruded shapes.

6 Inside coating only.

TABLE 2

Approximate Radii for 90° Cold Bend Aluminum and Aluminum Alloy Sheet

Minimum permissible radius[1] varies with nature of forming operation, type of forming equipment and design and condition of tools. Minimum working radius for given material or hardest alloy and temper for a given radius can be ascertained only by actual trial under contemplated conditions of fabrication.

See Table 17 for thicknesses of sheet available in tempers produced by cold rolling.

Alloy and Temper	Bend Classification[2]	Alloy and Temper	Bend Classification[2]
2S-O	A	24S-O (3)	B
2S-¼H	B	24S-T (3) (4)	J
2S-½H	B	24S-RT (3)	K
2S-¾H	D		
2S-H	F	52S-O	A
		52S-¼H	C
3S-O	A	52S-½H	D
3S-¼H	B	52S-¾H	F
3S-½H	C	52S-H	G
3S-¾H	E		
3S-H	G	61S-O	B
		61S-W	E
		61S-T	F

[1] See page 73.

[2] For corresponding bend radii see table below.

[3] Alclad 24S can be bent over slightly smaller radii than the corresponding tempers of the uncoated alloy.

[4] Immediately after quenching, these alloys can be formed over appreciably smaller radii.

Radii Required for 90° Bend in Terms of Thickness, t

	Approximate Thickness					
B & S Gauge Inch Inch	26 0.016 1/64	20 0.032 1/32	14 0.064 1/16	8 0.128 1/8	5 0.182 3/16	2 0.258 1/4
Bend Classification A	0	0	0	0	0	0
B	0	0	0	0	0–1t	0–1t
C	0	0	0	0–1t	0–1t	½t–1½t
D	0	0	0–1t	½t–1½t	1t–2t	1½t–3t
E	0–1t	0–1t	½t–1½t	1t–2t	1½t–3t	2t–4t
F	0–1t	½t–1½t	1t–2t	1½t–3t	2t–4t	2t–4t
G	½t–1½t	1t–2t	1½t–3t	2t–4t	3t–5t	4t–6t
H	1t–2t	1½t–3t	2t–4t	3t–5t	4t–6t	4t–6t
J	1½t–3t	2t–4t	3t–5t	4t–6t	4t–6t	5t–7t
K	2t–4t	3t–5t	3t–5t	4t–6t	5t–7t	6t–10t

TABLE 3

Recommended Conditions for Heat Treatment of Aluminum Alloys

Alloy	Solution Heat Treatment				Precipitation Heat Treatment		
	Temperature Degrees F.	Approximate Time of Heating	Quench	Temper Designation	Temperature Degrees F.	Approximate Time of Heating, Hours	Temper Designation
11S	930–980	(1)	(2)	11S-W	320–340	12–18	11S-T
14S (4)	925–950	(1)	(2)	14S-W	335–345 315–325	8–12 16–20	14S-T
17S	925–950	(1)	(2)	....	Room	48–96 (3)	17S-T
A17S	875–950	(1)	(2)	....	Room	48–96 (3)	A17S-T
18S	950–970	(1)	(2)	18S-W	335–345	8–12	18S-T
24S (4)	910–930	(1)	(2)	....	Room 370–380 (5) 370–380 (5)	48–96 (3) 11–13 8–10	24S-T 24S-T81 24S-T84 24S-T86
25S	950–970	(1)	(2)	25S-W	335–345	8–12	25S-T
32S	950–970	(1)	(2)	32S-W	335–345	6–10	32S-T
A51S	960–980	(1)	(2)	A51S-W	335–345	6–10	A51S-T
53S	960–980	(1)	(2)	53S-W	315–325 345–355	16–20 6–10	53S-T
61S	960–980	(1)	(2)	61S-W	315–325 345–355	16–20 6–10	61S-T
75S (4)	860-930(6)	(1)	(2)	75S-W	245–255 205–215 followed by 310–320	22–26 4– 6 (7) 8–10 (7)	75S-T

[1] The time of heating varies considerably, depending on the product, the type of furnace, and the size of the furnace charge. For sheet heat treated in a molten salt bath, the time may be as short as 10 minutes for thin material or as much as 60 minutes for thick material. In an air furnace, proper allowance must be made for the slower rate of bringing the load up to temperature. A minimum time of 4 hours is suggested for average forgings.

[2] The quench should be as rapid as possible and normally is accomplished by plunging the heated parts into a tank of cold water as quickly as possible after they have been removed from the furnace. Heavy forgings, however, are usually quenched in water at 150 to 212°F.

[3] More than 90 per cent of the maximum properties are obtained during the first day of aging.

[4] Alclad sheet is heat treated under the same conditions as the core alloy but the shortest heat-treatment time consistent with securing the required properties should be used and repeated heat treatments must be avoided.

[5] Cold working of the material subsequent to the solution heat treatment and prior to the precipitation treatment is necessary to secure the required properties. Precipitation heat treatment times significantly less than those shown may result in an unsatisfactory resistance to corrosion.

[6] Extrusions of 75S alloy must be heat treated within the temperature range 860–880°F.

[7] This is a two-stage treatment, with air cooling to room temperature between the low-temperature and the high-temperature stages. Anyone planning to use it may wish to consult his patent counsel regarding U.S. Patent No. 1,858,092.

TABLE 4

Approximate Tempers of Rolled and Cold-Finished Bar and Rod—2S, 3S

Shape	Diameter or Least Distance Across Flats, Inches	Approximate Temper[1]	
		Rolled	Cold-Finished
Rounds, Squares, Hexagons, Octagons	3/8" to 3/4" inclusive		1/2H to 3/4H
	Greater than 3/4" to 1 1/2"		1/2H to 3/4H
	Greater than 1 1/2" to 8"	1/8H to 1/4H	
Rectangles	Up to 1/8" inclusive	1/4H to 1/2H	1/2H to 3/4H
	Greater than 1/8" to 1/2"	1/4H to 1/2H	1/2H
	Greater than 1/2" to 1 1/2"	1/4H	1/4H
	Greater than 1 1/2" to 8"	1/8H to 1/4H	

[1] Tempers shown are *approximate*. Minimum tensile strengths are not guaranteed, but experience indicates that the tempers shown for various commodities may normally be expected. The small sizes tend to run harder than the large sizes, since they finish colder from the rolls; also, cold finishing introduces a greater percentage of reduction in cross-sectional area, hence more strain hardening. *Typical* or *average* properties (*not minimum*) for the various alloys in the various tempers are shown in Table 12.

TABLE 5

Nominal Composition of Wrought Aluminum Alloys[1]

Alloy	Per Cent of Alloying Elements—Aluminum and Normal Impurities Constitute Remainder								
	Copper	Silicon	Manganese	Magnesium	Zinc	Nickel	Chromium	Lead	Bismuth
2S	...	...	...	...	....	...	....	...	...
3S	...	...	1.2	...	....	...	....	...	...
11S	5.5	...	...	...	....	...	....	0.5	0.5
14S	4.4	0.8	0.8	0.4	....	...	....	...	...
17S	4.0	...	0.5	0.5	....	...	....	...	...
A17S	2.5	...	...	0.3	....	...	....	...	...
18S	4.0	...	...	0.5	....	2.0	....	...	...
24S	4.5	...	0.6	1.5	....	...	....	...	...
25S	4.5	0.8	0.8	...	....	...	....	...	...
32S	0.9	12.5	...	1.0	....	0.9	....	...	...
A51S	...	1.0	...	0.6	....	...	0.25	...	...
52S	...	...	...	2.5	....	...	0.25	...	...
53S	...	0.7	...	1.3	....	...	0.25	...	...
56S	...	...	0.1	5.2	....	...	0.1	...	...
61S	0.25	0.6	...	1.0	....	...	0.25	...	...
63S	...	0.4	...	0.7	....	...	....	...	...
75S	1.6	...	0.2	2.5	5.6	...	0.3	...	...

[1] Heat-treatment symbols have been omitted since composition does not vary for different heat-treatment practices.

TABLE 6

Nominal Composition of Aluminum Sand-Casting Alloys[1]

Alloy	Per Cent of Alloying Elements—Aluminum and Normal Impurities Constitute Remainder						
	Copper	Silicon	Magnesium	Zinc	Nickel	Manganese	Iron
43	....	5.0	....	...	...	...	...
108	4.0	3.0	....	...	...	...	...
112	7.0	....	....	1.7	...	...	...
113	7.0	2.0	....	1.7	...	...	...
122	10.0	....	0.2	....	...	...	...
142	4.0	....	1.5	....	2.0	...	...
195	4.5	0.8	....	....	...	...	...
212	8.0	1.2	....	....	...	...	...
214	....	....	3.8	....	...	...	...
B214	....	1.8	3.8	....	...	...	...
F214	....	0.5	3.8	....	...	...	...
220	....	....	10.0	....	...	...	...
319	3.5	6.0	....	....	...	...	...
355	1.3	5.0	0.5	....	...	...	...
356	....	7.0	0.3	....	...	...	...
406	....	....	....	....	...	2.0	...
645	2.7	....	....	10.5	...	...	1.2

[1] Heat-treatment symbols have been omitted since composition does not vary for different heat-treatment practices.

TABLE 7

Nominal Composition of Aluminum Permanent-Mold Casting Alloys[1]

Alloy	Per Cent of Alloying Elements—Aluminum and Normal Impurities Constitute Remainder					
	Copper	Silicon	Magnesium	Zinc	Nickel	Tin
43	...	5.0	...	...	...	...
A108	4.5	5.5	...	...	...	...
113	7.0	2.0	...	1.7	...	...
C113	7.0	3.5	...	...	...	...
122	10.0	...	0.2	...	...	...
A132	0.8	12.0	1.2	...	2.5	...
138	10.0	4.0	0.3	...	...	...
142	4.0	...	1.5	...	2.0	...
152	7.0	5.5	0.3	...	...	...
B195	4.5	2.5	...	...	...	...
A214	...	...	3.8	1.8	...	...
319	3.5	6.0	...	...	...	...
333	3.8	9.0	0.4	...	...	...
355	1.3	5.0	0.5	...	...	...
356	...	7.0	0.3	...	...	...
750	1.0	...	...	...	1.0	6.5

[1] Heat-treatment symbols have been omitted since composition does not vary for different heat-treatment practices.

TABLE 8

Nominal Composition of Aluminum Die-Casting Alloys

Alloy	Per Cent of Alloying Elements—Aluminum and Normal Impurities Constitute Remainder		
	Copper	Silicon	Magnesium
13 (1)	...	12.0	...
43	...	5.0	...
85	4.0	5.0	...
218	...	...	8.0
360 (1)	...	9.5	0.5
380 (1)	3.5	8.5	...

[1] The alloys A13, A360, and A380 have the same nominal compositions as 13, 360, and 380, respectively, but the impurities, notably iron, are controlled to closer limits.

TABLE 9

Typical Properties of Wrought Alloys

Alloy	Specific Gravity	Weight, Lb. per Cu. In.	Approximate Melting Range Degrees F.	Electrical Conductivity, Per Cent of International Annealed Copper Standard	Thermal Conductivity at 25° C., C. G. S. Units
2S-O	2.71	0.098	1190–1215	59	0.53
2S-H	2.71	0.098		57	0.52
3S-O	2.73	0.099	1190–1210	50	0.46
3S-¼H	2.73	0.099		42	0.39
3S-½H	2.73	0.099		41	0.38
3S-H	2.73	0.099		40	0.37
11S-T3	2.82	0.102	995–1190	40	0.37
14S-O	2.80	0.101	950–1180	50	0.46
14S-T	2.80	0.101		40	0.37
17S-O	2.79	0.101	955–1185	45	0.41
17S-T	2.79	0.101		30	0.29
A17S-T	2.74	0.099	950–1200	40	0.37
18S-O	2.80	0.101	945–1180	50	0.46
18S-T	2.80	0.101		40	0.37
24S-O	2.77	0.100	935–1180	50	0.45
24S-T	2.77	0.100		30	0.29
25S-T	2.79	0.101	970–1185	40	0.37
32S-O	2.69	0.097	990–1060	40	0.37
32S-T	2.69	0.097		35	0.33
A51S-O	2.69	0.097	1025–1200	55	0.50
A51S-W or T	2.69	0.097		45	0.41
52S-O	2.68	0.097	1100–1200	35	0.33
52S-H	2.68	0.097		35	0.33
53S-O	2.69	0.097	1075–1205	45	0.41
53S-W or T	2.69	0.097		40	0.37
56S-O	2.64	0.095	1055–1180	29	0.28
56S-H	2.64	0.095		27	0.26
61S-O	2.70	0.098	1080–1205	45	0.41
61S-W or T	2.70	0.098		40	0.37
75S-O	2.80	0.101	890–1180	..	....
75S-T	2.80	0.101		30	0.29
Brass	8.4–8.8	0.304–0.319	....	26–43	0.29–0.44
Copper	8.94	0.322	....	100	0.90
Magnesium	1.74	0.063	....	38	0.37
Monel	8.8	0.318	....	4	0.06
Nickel	8.84	0.319	....	16	0.14
Steel	7.6–7.8	0.276–0.282	....	3–15	....
Tin	7.3	0.265	....	15	0.15
Zinc	7.1	0.258	....	30	0.27

TABLE 10

Typical Properties of Casting Alloys

Alloy	Specific Gravity	Weight, Lb. per Cu. In.	Approximate Solidification Range Degrees F.	Electrical Conductivity, Per Cent of International Annealed Copper Standard	Thermal Conductivity at 25°C., C. G. S. Units[1]
13*	2.66	0.096	1090–1065	31	0.29
A13*	2.66	0.096	1090–1065	34	0.32
43	2.69	0.097	1175–1070	38	0.35
43 annealed (2)	2.69	0.097	1175–1070	42	0.39
45	2.68	0.097	1155–1070	31	0.29
45 annealed (2)	2.68	0.097	1155–1070	33	0.31
45*	2.68	0.097	1155–1070	41	0.38
85*	2.78	0.101	1155– 970	30	0.29
108	2.79	0.101	1170– 970	31	0.29
108 annealed (2)	2.79	0.101	1170– 970	38	0.35
A108*	2.79	0.101	1140– 960	37	0.34
112	2.91	0.105	1175–1005	30	0.29
112 annealed (2)	2.91	0.105	1175–1005	38	0.35
113*	2.91	0.105	1165– 975	30	0.28
113 annealed* (2)	2.91	0.105	1165– 975	38	0.35
C113	2.91	0.105	1165– 975	27	0.26
122-T2	2.95	0.106	1160–1005	41	0.38
122-T61	2.95	0.106	1160–1005	33	0.31
122*	2.95	0.106	1160–1005	34	0.32
A132-T551*	2.68	0.097	1095–1000	29	0.28
138*	2.95	0.106	1120– 940	25	0.25
142-T21	2.81	0.101	1165– 995	44	0.40
142-T571*	2.81	0.101	1165– 995	34	0.32
142-T77	2.81	0.101	1165– 995	37	0.36
142-T61*	2.81	0.101	1165– 995	32	0.31
152*	2.89	0.104	1110– 930	24	0.24
195-T4	2.81	0.101	1195–1020	35	0.33
195-T62	2.81	0.101	1195–1020	37	0.35
B195-T4*	2.78	0.101	1160– 980	35	0.33
B195-T6*	2.78	0.101	1160– 980	50	0.45
B195-T62	2.78	0.101	1160– 980	..	....
212	2.89	0.104	1165– 975	30	0.29
214	2.65	0.096	1185–1075	35	0.33
214 annealed (2)	2.65	0.096	1185–1075	35	0.33
A214*	2.65	0.096	1180–1050	33	0.31
B214	2.65	0.096	1170–1090	38	0.35
F214	2.65	0.096	1170–1090	36	0.34
218*	2.53	0.091	1140– 990	24	0.24
220-T4	2.58	0.093	1150– 840	21	0.21

TABLE 10—*Concluded*

Typical Properties of Casting Alloys

Alloy	Specific Gravity	Weight, Lb. per Cu. In.	Approximate Solidification Range Degrees F.	Electrical Conductivity, Per Cent of International Annealed Copper Standard	Thermal Conductivity at 25°C., C. G. S. Units[1]
319	2.77	0.100	1120– 950	27	0.26
319*	2.77	0.100	1120– 950	28	0.28
355-T51	2.70	0.098	1160–1075	43	0.40
355-T6	2.70	0.098	1160–1075	36	0.34
355-T61	2.70	0.098	1160–1075	37	0.35
355-T7	2.70	0.098	1160–1075	42	0.39
355-T6*	2.70	0.098	1160–1075	39	0.36
356-T51	2.68	0.097	1130–1075	43	0.40
356-T6	2.68	0.097	1130–1075	39	0.36
356-T7	2.68	0.097	1130–1075	40	0.37
356-T6*	2.68	0.097	1130–1075	41	0.38
360*	2.68	0.097	1105–1035	28	0.27
A360*	2.68	0.097	1105–1035	31	0.29
380*	2.76	0.099	1095– 985	23	0.23
A380*	2.76	0.099	1095– 985	26	0.26
406	2.74	0.099	1255–1215	25	0.24
645	3.00	0.108	1165– 980	33	0.31
645 annealed (2)	3.00	0.108	1165– 980	35	0.33
750*	2.89	0.104	1200– 450	45	0.42

*Chill cast samples; all other samples cast in green sand molds.

[1] C.G.S. units = calories per second per square centimeter per centimeter of thickness per degree Centigrade.

[2] While castings are not commonly annealed, similar effects on conductivities may result from the slower rate of cooling of thick sections as compared with thin ones and other variables in foundry practices. Comparison of the values for as-cast and annealed specimens will show the extent to which variations may be expected, depending upon differences in thermal conditions in the production of different types of castings.

TABLE 11

Average Coefficient of Thermal Expansion per Degree Fahrenheit[1]

Alloy	Temperature Range			
	−76° to +68°F.	68° to 212°F.	68° to 392°F.	68° to 572°F.
2S-O	12.1	13.1	13.7	14.2
3S-O	11.9	12.9	13.4	13.9
11S-T3	11.8	12.7	....	....
14S-O	....	12.5	13.1	13.6
14S-T	11.9	12.8	....	....
17S-O	....	12.8	13.3	13.9
17S-T	12.0	13.1	....	....
A17S-T	12.1	13.2	....	....
18S-O	....	12.4	12.9	13.4
18S-T	11.6	12.6	....	....
24S-O	....	12.7	13.3	13.7
24S-T	11.9	12.9	....	....
25S-O	....	12.7	13.2	13.6
25S-T	12.0	12.9	....	....
32S-O	....	10.8	11.3	11.7
32S-T	10.2	11.1	....	....
43	....	12.2	12.7	13.3
A51S-O	....	12.8	13.4	13.9
A51S-T	12.0	12.9	....	....
52S-O	12.2	13.2	13.8	14.3
53S-O	....	12.7	13.4	13.9
53S-T	12.1	13.1	....	....
56S-O	12.4	13.5	14.1	14.6
61S-O	....	13.1	13.5	14.1
61S-T	12.0	13.1	....	....
75S-O	....	12.9	13.4	14.4
75S-T	12.0	13.1	....	....
A108	....	11.9	12.5	12.7
108, 112, C113	....	12.2	12.7	13.3
122	....	12.2	12.7	13.0
A132	....	10.5	11.1	11.6
138	....	11.9	12.5	12.7
142	....	12.5	13.0	13.6
195	....	12.7	13.3	13.8
B195	....	12.2	12.7	13.3
212	....	12.2	12.7	13.3
214, A214	....	13.3	13.8	14.4
220	....	13.6	14.1	14.7
355	....	12.2	12.7	13.3
356	....	11.9	12.7	13.0
645	....	13.0	13.6	14.0
Brass	....	9.7 to 10.7	10.2 to 11.7	....
Cast Iron	....	5.9	....	....
Copper	....	9.3	....	....
Lead	....	17.0	....	....
Monel	....	7.8	....	....
Nickel	....	7.2	....	....
Steel	....	6.0 to 7.0	....	....
Zinc	....	18.0	....	....

[1] To be multiplied by 10^{-6} (for example, the coefficient of thermal expansion for 2S-O in column 2 is 12.1 x 10^{-6}, which is 0.0000121).

TABLE 12

Typical[1] Mechanical Properties of Wrought Aluminum Alloys[2]

Alloy and Temper	TENSION				HARDNESS	SHEAR	FATIGUE
	Yield Strength[3] (Set=0.2%), Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation,[2] Per Cent in 2 In.		Brinell, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit,[2] Lb./Sq. In.
			Sheet Specimen (1/16 Inch Thick)	Round Specimen (1/2 Inch Diameter)			
2S-O	5,000	13,000	35	45	23	9,500	5,000
2S-¼H	13,000	15,000	12	25	28	10,000	6,000
2S-½H	14,000	17,000	9	20	32	11,000	7,000
2S-¾H	17,000	20,000	6	17	38	12,000	8,500
2S-H	21,000	24,000	5	15	44	13,000	8,500
3S-O	6,000	16,000	30	40	28	11,000	7,000
3S-¼H	15,000	18,000	10	20	35	12,000	8,000
3S-½H	18,000	21,000	8	16	40	14,000	9,000
3S-¾H	21,000	25,000	5	14	47	15,000	9,500
3S-H	25,000	29,000	4	10	55	16,000	10,000
11S-T3 (3)	47,000	53,000	..	15	95	30,000	12,500
11S-T8	44,000	57,000	..	14	100	33,000	......
14S-O	14,000	27,000	..	18	45	18,000	11,000
14S-W	40,000	62,000	..	25	100	34,000	18,000
14S-T	60,000	70,000	..	13	135	42,000	18,000
Alclad 14S-O	10,000	25,000	21	..	..	18,000	......
Alclad 14S-W	38,000 (4)	59,000 (4)	18	..	..	39,000	......
Alclad 14S-T	58,000 (4)	65,000 (4)	9	..	..	41,000	......
17S-O	10,000	26,000	..	22	45	18,000	11,000
17S-T	40,000	62,000	..	22	105	38,000	18,000
A17S-T	24,000	43,000	..	27	70	28,000	13,500
24S-O	11,000	27,000	19	22	42	18,000	12,000
24S-T	46,000	68,000	19	22	120	41,000	18,000
24S-RT	57,000	73,000	13	..	130	42,000	......
Alclad 24S-T	43,000 (4)	64,000 (4)	18	..	..	40,000	......
Alclad 24S-RT	53,000 (4)	67,000 (4)	11	..	..	41,000	......
Alclad 24S-T81	60,000 (4)	66,000 (4)	7	..	..	......	......
Alclad 24S-T86	66,000 (4)	70,000 (4)	6	..	..	......	......
52S-O	14,000	29,000	25	30	45	18,000	17,000
52S-¼H	26,000	34,000	12	18	62	20,000	17,500
52S-½H	29,000	37,000	10	14	67	21,000	18,000
52S-¾H	34,000	39,000	8	10	74	23,000	18,500
52S-H	36,000	41,000	7	8	85	24,000	19,000
53S-O	7,000	16,000	..	35	26	11,000	8,000
53S-W	20,000	33,000	..	30	65	20,000	13,000
53S-T	33,000	39,000	..	20	80	24,000	13,000
56S-O	20,000	42,000	..	35	..	......	20,000
56S-H	48,000	58,000	..	7	..	......	22,000
61S-O	8,000	18,000	22	30	30	12,500	9,000
61S-W	21,000	35,000	22	25	65	24,000	13,500
61S-T	40,000	45,000	12	17	95	30,000	13,500
63S as extruded	17,000	23,000	..	17	..	14,000	......
63S-T5	24,000	31,000	..	14	..	19,000	......
75S-O	15,000	33,000	17	11	..	......	......
75S-T	72,000	82,000	11	10	150	47,000	22,500
Alclad 75S-O	14,000	32,000	17	..	..	......	......
Alclad 75S-T	67,000	76,000	11	..	..	46,000	......

[1] For guaranteed minimum values, see Tables 17 to 25.
[2] See page 88 for definitions and significance of terms; also additional data. See Table 18 for forging alloys.
[3] For sizes up to 1½ inches. For larger sizes values are lower.
[4] Sheet over 0.063 inch thick will have slightly higher tensile and yield strengths.

TABLE 13

Mechanical Properties of Aluminum Sand-Casting Alloys[1]

(See "Design of Aluminum Alloy Castings," page 67.)

ALLOY	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tension[2]		Tension[2]			Compression[3]	Hardness[2]	Shear	Fatigue
	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Brinell, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit,[1] Lb./Sq. In.
43	17,000	3.0	9,000	19,000	6.0	10,000	40	14,000	6,500
108	19,000	1.5	14,000	21,000	2.5	14,000	55	20,000	8,000
112	19,000	(4)	15,000	24,000	1.5	17,000	70	20,000	9,000
113	19,000	(4)	15,000	24,000	1.5	17,000	70	20,000	9,000
122–T2	23,000	(4)	20,000	27,000	1.0	20,000	80	21,000	9,500
122–T61	30,000	(4)	30,000	40,000	(6)	43,000	115	29,000	8,500
142–T21	23,000	(4)	18,000	27,000	1.0	18,000	70	21,000	6,500
142–T571	29,000	(4)	28,000	32,000	0.5	34,000	85	27,000	8,000
142–T77	21,500	(4)	25,000	28,000	2.0	......	75	24,000	9,500

TABLE 13—*Continued*

Mechanical Properties of Aluminum Sand-Casting Alloys[1]

ALLOY	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tension[2]		Tension[2]			Compression[3]	Hardness[2]	Shear	Fatigue
	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Brinell, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit,[1] Lb./Sq. In.
195–T4 ([5])	29,000	6.0	16,000	32,000	8.5	16,000	60	24,000	6,000
195–T6	32,000	3.0	24,000	36,000	5.0	25,000	75	30,000	6,500
195–T62	36,000	([4])	30,000	40,000	2.0	38,000	95	31,000	7,000
212	19,000	([4])	14,000	23,000	2.0	14,000	65	20,000	8,000
214	22,000	6.0	12,000	25,000	9.0	12,000	50	20,000	5,500
B214	17,000	([4])	13,000	20,000	2.0	15,000	50	17,000	......
F214	17,000	([4])	12,000	20,000	3.0	......	50	......	......
220–T4	42,000	12.0	25,000	46,000	14.0	26,000	75	33,000	7,000
319	25,000	([4])	17,000	29,000	1.5	......	70	......	10,000
319–T6	31,000	1.5	24,000	36,000	2.0	......	80	......	10,000

Continued on next page.

TABLE 13—*Concluded*

Mechanical Properties of Aluminum Sand-Casting Alloys[1]

ALLOY	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tension[2]		Tension[2]			Compression[3]	Hardness[2]	Shear	Fatigue
	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Brinell, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit,[1] Lb./Sq. In.
355–T51	25,000	(4)	23,000	28,000	1.5	24,000	65	22,000	7,000
355–T6	32,000	2.0	25,000	35,000	2.5	29,000	80	30,000	8,500
355–T61	36,000	(4)	35,000	39,000	1.0	37,000	90	32,000	.....
355–T7	35,000	(4)	36,000	38,000	0.5	35,000	85	26,000	8,500
355–T71	30,000	(4)	29,000	35,000	1.5	......	75	......	10,000
356–T51	23,000	(4)	20,000	25,000	2.0	22,000	60	18,000	7,500
356–T6	30,000	3.0	24,000	33,000	4.0	22,000	70	27,000	8,000
356–T7	31,000	(4)	30,000	34,000	2.0	29,000	75	18,000	.....
356–T71	25,000	3.0	21,000	28,000	4.5	......	60	16,000	.....
406	16,000	6.5	9,000	19,000	12.0	9,000	35	14,000	5,500
645 (5)	25,000	2.5	17,000	29,000	4.0	20,000	70	22,000	7,500

[1] See page 88 for definitions and significance of terms; also additional data.

[2] Tension and hardness values determined from standard half-inch diameter tensile test specimens individually cast in green sand molds and tested without machining off the surface.

[3] Results of tests on specimens having an l/r ratio of 12.

[4] Not specified. The error in determining low elongations is comparable with the value being measured.

[5] On standing at room temperature for several weeks the tensile and yield strengths will increase somewhat and the elongation will be reduced slightly. In the case of 195-T4, the properties will approach those of the T6 condition.

[6] Less than 0.5 per cent.

TABLE 14

Mechanical Properties of Aluminum Permanent-Mold Casting Alloys[1]

(See "Design of Aluminum Alloy Castings," page 67.)

ALLOY	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tension[2]		Tension[2]			Compression[3]	Hardness[2]	Shear	Fatigue
	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Brinell, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit,[1] Lb./Sq. In.
43	21,000	5.0	9,000	24,000	9.0	9,000	45	18,000	.....
A108	24,000	(4)	16,000	28,000	2.0	16,000	70	25,000	.....
113	24,000	(4)	19,000	28,000	2.0	19,000	70	23,000	.....
C113	25,000	(4)	24,000	30,000	1.0	24,000	80	22,000	9,500
122–T52	30,000	(4)	31,000	35,000	1.0	31,000	100	25,000	.....
122–T551	30,000	(4)	35,000	37,000	(6)	40,000	115	27,000	8,500
122–T65	40,000	(4)	36,000	48,000	(6)	36,000	140	30,000	9,000
A132–T551	31,000	(4)	28,000	36,000	0.5	30,000	105	24,000	.....
A132–T65	40,000	(4)	......	47,000	0.5	......	125	27,000	.....
138	26,000	(4)	24,000	28,000	0.5	32,000	100	22,000	.....
142–T571	34,000	(4)	34,000	40,000	1.0	34,000	105	26,000	10,500
142–T61	40,000	(4)	42,000	47,000	0.5	46,000	110	31,000	9,500

Continued on next page.

TABLE 14—*Continued*

Mechanical Properties of Aluminum Permanent-Mold Casting Alloys[1]

ALLOY	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tension[2]		Tension[3]			Compression[3]	Hardness[2]	Shear	Fatigue
	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Brinell, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit,[1] Lb./Sq. In.
152–T524	27,000	(4)	16,000	29,000	1.0	......	95	22,000	.....
152–T74	30,000	(4)	26,000	35,000	0.5	......	100	29,000	.....
B195–T4 (5)	33,000	4.5	22,000	40,000	10.0	22,000	75	30,000	9,500
B195–T6	35,000	2.0	33,000	45,000	5.0	33,000	90	32,000	10,000
B195–T7	33,000	3.0	20,000	39,000	4.5	......	80	......	.....
A214	22,000	2.5	16,000	27,000	7.0	17,000	60	22,000	.....
319	28,000	1.5	19,000	34,000	2.5	......	85	......	.....
319–T6	34,000	2.0	27,000	40,000	3.0	......	95	......	.....
333–T533	30,000	(4)	25,000	32,000	1.0	......	100	......	.....
355–T51	27,000	(4)	24,000	30,000	2.0	24,000	75	24,000	.....
355–T6	37,000	1.5	27,000	43,000	4.0	26,000	90	30,000	9,000
355–T62	42,000	(4)	40,000	45,000	1.5	......	105	36,000	.....
355–T7	36,000	(4)	30,000	40,000	2.0	......	85	30,000	.....
355–T71	34,000	(4)	31,000	36,000	3.0	......	85	26,000	.....

TABLE 14—*Concluded*

Mechanical Properties of Aluminum Permanent-Mold Casting Alloys[1]

ALLOY	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tension[2]		Tension[2]			Compression[3]	Hardness[2]	Shear	Fatigue
	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Yield Strength[1] (Set = 0.2%), Lb./Sq. In.	Brinell, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit,[1] Lb./Sq. In.
356–T6	33,000	3.0	27,000	40,000	5.0	24,000	90	......	.....
356–T7	29,000	4.0	......	33,000	5.0	......	70	......	.....
750–T533	18,000	8.0	8,500	20,000	10.0	8,500	45	14,000	9,000

1 See page 88 for definitions and significance of terms; also additional data.

2 Tension and hardness values obtained from standard half-inch diameter tensile test specimens, individually cast in a permanent mold, and tested without machining off the surface.

3 Results of tests on specimens having an l/r ratio of 12.

4 Not specified. The error in determining low elongations is comparable with the value being measured.

5 On standing at room temperature for several weeks, properties approach those of the T6 condition.

6 Less than 0.5 per cent.

TABLE 15

Typical Mechanical Properties of Aluminum Die-Casting Alloys[1]

Alloy[3]	Typical Mechanical Properties[1, 2]			
	Tensile Strength,[2] Lb./Sq. In.	Yield Strength,[1] Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Endurance Limit,[1] Lb./Sq. In.
13	37,000	18,000	1.8	15,000
A13	35,000	16,000	3.5	......
43	30,000	14,000	7.0	......
85	40,000	22,000	3.5	17,000
218	42,000	23,000	7.0	18,000
360	42,000	23,000	1.8	......
A360	40,000	20,000	4.5	......
380	45,000	25,000	2.0	......
A380	42,000	23,000	4.0	......

[1] See page 88 for definitions and significance of terms; also additional data.

[2] Tensile properties are average values obtained from A.S.T.M. standard round die-cast test specimen, ¼ inch in diameter, produced on a cold chamber (high pressure) die casting machine.

[3] The alloys whose numbers are prefixed by "A" differ from those without the prefix in that the impurities, notably iron, are controlled to lower limits.

TABLE 16

Typical Tensile Properties at Elevated Temperatures Wrought Aluminum Alloys

(After Prolonged Heating at Testing Temperature)

Alloy	Temperature, Deg. F.	Strength, Lb./Sq. In.		Elongation, % n 2 In.	Alloy	Temperature, Deg. F.	Strength, Lb./Sq. In.		Elongation, % in 2 In.
		Yield	Tensile				Yield	Tensile	
2S-O	75	5,000	13,000	45	17S-T	75	40,000	62,000	22
	300	3,500	7,500	65		300	35,000	41,000	18
	400	3,000	6,000	70		400	11,000	17,000	33
	500	2,000	3,500	85		500	7,000	10,000	50
	600	1,500	2,500	90		600	4,000	6,000	80
	700	1,000	1,500	95		700	3,000	4,000	100
2S-½H	75	14,000	17,000	20	A17S-T	75	24,000	43,000	27
	300	10,000	13,000	22		300	26,000	30,000	20
	400	6,500	9,500	25		400	13,000	17,000	30
	500	2,000	3,500	85		500	5,500	8,000	45
	600	1,500	2,500	90		600	3,000	4,500	70
	700	1,000	1,500	95		700	2,000	3,000	90
2S-H	75	21,000	24,000	15	18S-T	75	47,000	63,000	17
	300	14,000	17,500	16		300	44,000	49,000	10
	400	3,000	6,000	70		400	17,000	22,000	15
	500	2,000	3,500	85		500	7,000	11,000	32
	600	1,500	2,500	90		600	4,000	6,000	55
	700	1,000	1,500	95		700	2,500	4,000	85
3S-O	75	6,000	16,000	40	24S-T	75	46,000	68,000	22
	300	5,000	11,000	47		300	37,000	42,000	20
	400	4,500	8,000	50		400	16,000	20,000	26
	500	3,500	5,500	60		500	10,000	12,000	40
	600	2,500	4,000	60		600	5,500	7,000	70
	700	2,000	3,000	60		700	3,500	5,000	100
3S-½H	75	18,000	21,000	16	25S-T	75	35,000	57,000	18
	300	15,000	18,000	17		300	28,000	35,000	20
	400	9,000	14,000	22		400	13,500	19,000	35
	500	5,000	10,500	25		500	6,000	9,000	45
	600	3,000	6,000	40		600	4,000	4,500	50
	700	2,000	3,000	60		700	3,000	3,500	55
3S-H	75	25,000	29,000	10	32S-T	75	46,000	56,000	8
	300	16,000	23,000	12		300	33,000	39,000	9
	400	8,000	17,000	15		400	11,000	16,000	30
	500	5,000	10,500	25		500	6,500	8,500	50
	600	3,000	4,500	55		600	3,500	6,000	60
	700	2,000	3,000	60		700	2,000	3,500	120
11S-T3	75	47,000	53,000	15	A51S-T	75	40,000	47,000	20
	300	18,000	27,000	25		300	15,000	19,000	28
	400	13,000	19,000	34		400	5,500	7,500	58
	500	4,500	8,500	44		500	4,500	5,500	59
	600	2,000	4,000	90		600	3,500	4,500	60
	700	1,000	2,500	125		700	3,000	3,500	65
14S-T	75	60,000	70,000	13	52S-O	75	14,000	29,000	30
	300	39,000	43,000	16		300	13,500	23,000	55
	400	13,000	17,000	33		400	11,000	18,000	65
	500	8,000	10,000	50		500	8,000	12,000	100
	600	4,500	6,000	65		600	4,000	7,500	105
	700	3,500	4,000	75		700	2,500	5,000	120

TABLE 16—*Continued*

Typical Tensile Properties at Elevated Temperatures

Wrought Aluminum Alloys

(After Prolonged Heating at Testing Temperature)

Alloy	Temperature, Deg. F.	Strength, Lb./Sq. In.		Elongation, % in 2 In.
		Yield	Tensile	
52S-3/4H	75	34,000	39,000	10
	300	27,000	32,000	16
	400	11,000	25,000	35
	500	8,000	12,000	80
	600	4,500	8,000	100
	700	2,500	5,000	120
53S-T	75	33,000	39,000	20
	300	22,000	25,000	17
	400	10,000	13,000	30
	500	3,500	6,000	70
	600	2,500	3,500	75
	700	2,000	2,500	90
61S-T	75	40,000	45,000	17
	300	29,000	31,000	18
	400	15,000	19,000	25
	500	5,000	7,500	55
	600	2,500	3,500	90
	700	2,000	3,000	105
75S-T	75	72,000	82,000	11
	300	22,000	28,000	32
	400	11,000	14,000	55
	500	8,000	11,000	60
	600	6,000	8,000	68
	700	4,000	6,000	75

TABLE 16—*Continued*

Typical Tensile Properties at Elevated Temperatures

Aluminum Permanent-Mold Casting Alloys

(After Prolonged Heating at Testing Temperature)

Alloy	Temperature, Deg. F.	Strength, Lb./Sq. In.		Elongation, % in 2 In.
		Yield	Tensile	
122-T551	75	35,000	37,000	[2]
	300	29,000	33,000	[2]
	400	20,000	26,000	1.0
	500	12,500	18,000	3.0
	600	6,000	10,000	10.0
A132-T551	75	28,000	36,000	0.5
	300	22,000	31,000	1.0
	400	13,500	23,000	2.0
	500	9,500	17,500	2.0
	600	5,000	11,000	8.0
142-T571	75	34,000	40,000	1.0
	300	33,000	37,000	1.0
	400	22,000	28,000	2.0
	500	9,000	15,000	10.0
	600	5,000	9,000	30.0
B195-T4[1]	75	22,000	40,000	10.0
	300	20,000	33,000	11.0
	400	9,000	17,000	15.0
	500	5,000	8,500	25.0
	600	2,500	4,000	65.0
355-T6	75	27,000	43,000	4.0
	300	29,000	33,000	2.0
	400	9,000	12,000	20.0
	500	6,000	8,000	25.0
	600	3,000	4,500	50.0

[1] The properties shown for temperatures of 300°F. and higher are also applicable to the T6 condition.

[2] Less than 0.5 per cent.

TABLE 16—*Concluded*

Typical Tensile Properties at Elevated Temperatures

Aluminum Sand-Casting Alloys

(After Prolonged Heating at Testing Temperature)

Alloy	Temperature, Deg. F.	Strength, Lb./Sq. In.		Elongation, % in 2 In.	Alloy	Temperature, Deg. F.	Strength, Lb./Sq. In.		Elongation, % in 2 In.
		Yield	Tensile				Yield	Tensile	
112	75	15,000	24,000	1.5	214	75	12,000	25,000	9.0
	300	24,000	25,000	1.5		300	15,000	23,000	7.0
	400	15,000	19,000	1.5		400	12,500	18,500	9.0
	500	10,000	15,000	3.5		500	8,000	13,500	12.0
	600	4,500	6,500	20.0		600	4,000	9,000	17.0
122-T2	75	20,000	27,000	1.0	355-T6	75	25,000	35,000	2.5
	300	17,000	25,000	1.0		300	25,000	30,000	1.5
	400	14,000	22,000	1.5		400	9,000	13,000	12.0
	500	11,000	17,000	3.0		500	5,000	8,000	22.0
	600	4,500	8,000	14.0		600	3,500	6,000	30.0
122-T61	75	30,000	40,000	(2)	355-T51	75	23,000	28,000	1.5
	300	30,000	35,000	1.0		300	17,000	22,000	2.5
	400	16,000	22,000	2.0		400	9,000	13,000	12.0
	500	5,000	10,000	6.0		500	5,000	8,000	22.0
	600	4,500	8,000	14.0		600	3,500	6,000	30.0
142-T21	75	18,000	27,000	1.0	356-T6	75	24,000	33,000	4.0
	300	18,000	27,000	1.0		300	16,000	21,000	5.0
	400	14,000	21,000	1.5		400	9,000	13,000	8.0
	500	8,000	16,000	3.0		500	5,500	8,000	20.0
	600	4,000	8,000	9.0		600	3,000	4,500	45.0
195-T4(1)	75	16,000	32,000	8.5					
	300	13,000	24,000	9.0					
	400	9,000	15,000	20.0					
	500	6,000	9,500	25.0					
	600	3,000	4,000	30.0					

[1] The properties shown for temperatures of 300°F. and higher are also applicable to the T6 condition.

[2] Less than 0.5 per cent.

TABLE 17

Mechanical Properties Specifications
Sheet and Plate 2S, 3S, 52S

SHEET

Grade and Temper	Tensile Strength, Lb./Sq. In. Minimum Except for Soft (O) Temper	Minimum Elongation,[1] Per Cent in 2 Inches								
		Thickness, Inch								
		.249"–.204"	.203"–.162"	.161"–.114"	.113"–.051"	.050"–.032"	.031"–.020"	.019"–.013"	.012"–.008"	.007"–.006"
2S-O	15,500 (2)	30	30	30	30	25	20	15	15	15
2S-¼H	14,000	9	9	9	8	6	4	3	..	..
2S-½H	16,000	6	6	6	5	4	3	2	1	..
2S-¾H	19,000	..	..	4	4	3	2	1	1	1
2S-H	22,000	..	..	4	4	3	2	1	1	1
3S-O	19,000 (2)	25	25	25	25	23	20	20	18	14
3S-¼H	17,000	8	8	7	6	5	4	3	..	..
3S-½H	19,500	7	7	6	5	4	3	2	1	..
3S-¾H	24,000	..	..	4	4	3	2	1	1	1
3S-H	27,000	..	..	4	4	3	2	1	1	1
52S-O	31,000 (2)	20	20	20	20	20	18	15	15	..
52S-¼H	31,000	9	9	9	7	5	5	4	..	..
52S-½H	34,000	7	7	7	6	4	4	3	3	..
52S-¾H	37,000	..	..	4	4	4	3	3	3	..
52S-H	39,000	..	..	4	4	4	3	3	3	..

PLATE

2S, 3S, 52S, As Rolled—No physical tests required. (See page 30.)

¼H, ½H { Physical properties same as for 0.249-inch sheet in same alloy and temper.

MAXIMUM AND MINIMUM COMMERCIAL THICKNESS OF FLAT AND COILED SHEET IN ALL TEMPERS

Temper	FLAT SHEET		COILED SHEET	
	Thickness, Inch		Thickness, Inch	
	Maximum	Minimum	Maximum	Minimum
O	0.249	0.006	0.102	0.006
¼H	0.249	0.017	0.102	0.017
½H	0.249	0.0095	0.085	0.0095
¾H	0.162	0.006	0.053	0.006
H	0.128	0.006	0.102	0.006

[1] Test specimens taken parallel to direction of rolling from flat and coiled sheet in ¼H and ½H tempers.

[2] Maximum. So specified to insure complete annealing.

TABLE 18

Mechanical Properties Specifications—Aluminum Alloy Forgings[1]

Alloy	Minimum Specification Values				Typical Values (Not Guaranteed)		
	Tension[2]			Hardness[2]	Shear	Fatigue	Density
	Yield Strength[1] (Set = 0.2%), Lb./Sq. In. Minimum	Ultimate Strength, Lb./Sq. In. Minimum	Elongation,[1] Per Cent in 2 Inches Minimum	Brinell, 500-kg. Load 10-mm. Ball Minimum	Shearing Strength, Lb./Sq. In.	Endurance Limit,[1] Lb./Sq. In.	Lb./Cu. In.
11S-T	33,000	53,000	12.0	90	31,000	13,000	0.102
14S-T	55,000	65,000	10.0	125	42,000	18,000	0.101
17S-T	30,000	55,000	16.0	100	38,000	18,000	0.101
18S-T	40,000	55,000	10.0	100	39,000	17,000	0.101
25S-T	30,000	55,000	16.0	100	35,000	18,000	0.101
32S-T	40,000	52,000	5.0	115	38,000	16,000	0.097
A51S-T	34,000	44,000	12.0	90	32,000	11,000	0.097
53S-T	30,000	36,000	14.0	75	24,000	13,000	0.097

[1] These properties apply to forgings up to 4 inches in diameter or thickness. Long axis of test specimen taken parallel to direction of grain flow. See page 88 for definitions and significance of terms; also additional data.

[2] Tension and hardness values determined from standard half-inch diameter test specimens. Values in compression at least equal to values in tension.

TABLE 19

Mechanical Properties Specifications—Bar and Rod, 11S[1]

(*For 11S Forgings, See Table 18.*)

	Dimensions,[1] Inches	Tensile Strength, Lb./Sq. In. Minimum	Yield Strength[1] (Set = 0.2%), Lb./Sq. In. Minimum	Elongation, Per Cent in 4D[1] Minimum
11S-T3				
Rounds and Hexagons	0.125 to 1.500	45,000	38,000	10
Rounds only	1.501 to 2.000	42,000	33,000	14
Rounds only	2.001 to 3.000	40,000	28,000	16
11S-T8				
Rounds and Hexagons	0.125 to 1.500	52,000	40,000	10
Rounds only	1.501 to 3.250	52,000	40,000	10

[1] See page 88 for definitions and significance of terms; also additional data.

TABLE 20

Mechanical Properties Specifications—17S Alloy Products[1]

Material	Dimensions,[1] Inches	Tensile Strength, Lb./Sq. In. Minimum Except for 17S-O[2]	Yield Strength[1] (Set=0.2%), Lb./Sq. In. Minimum	Elongation Per Cent in 2 Inches or in 4D[1], Minimum
Wire, Rod, Bar and Shapes				
17S-O Wire	up to 0.124	35,000 (2)	....	..
17S-O Bar, rod, shapes	0.125–8.000	35,000 (2)	....	12
17S-T Wire	up to 0.124	55,000	....	..
17S-T Rounds, squares, hexagons, octagons, (rolled)	0.125–8.000	55,000	32,000	16
17S-T Rectangular bars (rolled)	up to 3.000	55,000	32,000	16
17S-T Structural shapes (rolled)	....	55,000	32,000	16
17S-T Extruded shapes	....	50,000	35,000	12
Tubing				
17S-O	All sizes	35,000 (2)	....	..
17S-T	*Diameter ¼" to 2"* Wall thickness:			
	0.025–0.049	58,000	34,000 (3)	12
	0.050–0.259	58,000	34,000 (3)	14
	0.260–0.500	58,000	34,000 (3)	16
	Diameter greater than 2" to 8" Wall thickness:			
	0.025–0.049	58,000	34,000 (3)	10
	0.050–0.259	58,000	34,000 (3)	12
	0.260–0.500	58,000	34,000 (3)	14

[1] See page 88 for definitions and significance of terms; also additional data. For forgings see Table 18.

[2] Maximum. So specified to insure complete annealing.

[3] The tensile yield strength of 17S-T tubing usually exceeds this value by a substantial amount because of straightening operations.

TABLE 21

Mechanical Properties Specifications—14S Alloy Products[1]

Temper	Thickness,[1] Inch	Tensile Strength, Lb./Sq. In. Minimum Except for 14S-O[2]	Yield Strength[1] (Set = 0.2%), Lb./Sq. In. Minimum	Elongation Per Cent in 2 Inches or in 4D[1], Minimum
Sheet and Plate				
Alclad 14S-O	0.020–0.500	30,000 (2)	....	16
Alclad 14S-W				
Flat Sheet	0.020–0.039	55,000	35,000 (3)	14
	0.040–0.249	57,000 (3)	37,000 (3)	15
Coiled Sheet	0.020–0.039	55,000	32,000	15
	0.040–0.128	55,000	34,000	15
Plate	0.250–0.500	57,000 (3)	37,000 (3)	15
	0.501–1.000	58,000 (3)	34,000	10
Alclad 14S-T				
Flat or Coiled Sheet	0.020–0.039	63,000	56,000	7
	0.040–0.249	64,000	57,000	8
Plate	0.250–0.500	64,000	57,000	8
Extruded Shapes				
14S-O	All	35,000 (2)	....	12
14S-W	All	50,000	35,000	12
14S-T	0.125–0.499	60,000	53,000	7
	0.500–0.749	65,000 (3)	55,000 (3)	7
	0.750 and over (4)	68,000 (3)	58,000 (3)	7
Rolled Shapes				
14S-W	All	55,000	32,000	16
14S-T	All	65,000	55,000	8

1 See page 88 for definitions and significance of terms, and Table 12 for typica properties.

2 Maximum. So specified to insure complete annealing.

3 Flat sheet heat treated by the user cannot be required to have tensile and yield strengths higher than those shown for coiled sheet of a corresponding thickness. Plate heat treated by the user cannot be required to develop tensile and yield strengths higher than 55,000 and 34,000 pounds per square inch, respectively. Extruded shapes re-heat treated by the user, regardless of thickness, cannot be required to develop tensile and yield strengths higher than 60,000 and 50,000 pounds per square inch, respectively.

4 The properties apply to sections having a cross-sectional area of not over 25 square inches.

TABLE 22

Mechanical Properties Specifications—24S Alloy Products[1]

Material	Dimensions,[1] Inches	Tensile Strength, Lb./Sq. In. Minimum Except for 24S-O[2]	Yield Strength[1] (Set=0.2%), Lb./Sq. In. Minimum	Elongation Per Cent in 2 Inches or in 4D[1], Minimum
Sheet and Plate				
24S-O	0.010–0.500	35,000 (2)	......	12
24S-T Flat Sheet	0.010–0.020	64,000 (3)	42,000 (3)	12
	0.021–0.051	64,000 (3)	42,000 (3)	15
	0.052–0.128	64,000 (3)	42,000 (3)	17
	0.129–0.249	64,000 (3)	42,000 (3)	15
24S-T Coiled Sheet	0.012–0.020	62,000	40,000	12
	0.021–0.051	62,000	40,000	15
	0.052–0.064	62,000	40,000	17
24S-T Plate	0.250–0.500	62,000	40,000	12
	0.501–1.000	62,000	40,000	8
	1.001–1.500	60,000	40,000	7
	1.501–2.000	60,000	40,000	6
24S-RT Flat Sheet and Plate	0.020–0.031	69,000	52,000	10
	0.032–0.036	69,000	52,000	11
	0.037–0.188	69,000	52,000	12
	0.189–0.500	69,000	52,000	10
Alclad 24S-O	0.010–0.032	33,000 (2)	......	8
	0.033–0.063	33,000 (2)	......	10
	0.064–0.500	34,000 (2)	......	12
Alclad 24S-T Flat Sheet	0.010–0.020	59,000 (3)	39,000 (3)	12
	0.021–0.040	59,000 (3)	39,000 (3)	15
	0.041–0.063	59,000 (3)	39,000 (3)	15
	0.064–0.128	62,000 (3)	40,000 (3)	15
	0.129–0.249	62,000 (3)	40,000 (3)	13
Alclad 24S-T81 Flat Sheet	0.010–0.063	62,000	54,000	5
	0.064–0.249	65,000	56,000	5
Alclad 24S-T86 Flat Sheet	0.020–0.063	66,000	62,000	3
	0.064–0.249	70,000	66,000	3
Alclad 24S-T Coiled Sheet	0.012–0.020	56,000	37,000	12
	0.021–0.040	56,000	37,000	15
	0.041–0.063	56,000	37,000	15
	0.064	60,000	38,000	15
Alclad 24S-T Plate	0.250–0.500	62,000	40,000	11
Alclad 24S-RT Flat Sheet and Plate	0.020–0.031	62,000	48,000	8
	0.032–0.040	62,000	48,000	9
	0.041–0.063	62,000	48,000	10
	0.064–0.188	66,000	50,000	10
	0.189–0.500	66,000	50,000	9
Wire, Rod, Bar and Shapes				
24S-O Wire	up to 0.124 incl.	35,000 (2)	......	..
24S-O Bars, rods, shapes	0.125–8.000	35,000 (2)	......	12

TABLE 22—*Concluded*

Mechanical Properties Specifications—24S Alloy Products[1]

Material	Dimensions,[1] Inches	Tensile Strength, Lb./Sq. In. Minimum Except for 24S-O[2]	Yield Strength[1] (Set=0.2%), Lb./Sq. In. Minimum	Elongation Per Cent in 2 Inches or in 4D[1], Minimum
Wire, Rod, Bar and Shapes—Continued				
24S-T Wire	up to 0.124	62,000	......	..
24S-T Rounds (rolled)	0.125–5.500	62,000	40,000	12
24S-T Squares, hexagons, octagons (rolled)	0.125–4.000	62,000	40,000	12
24S-T Rectangular bars (rolled)	up to 24 sq. in. cross section	62,000	40,000	12
24S-T Extruded shapes	Section thickness:			
	0.050 to 0.249	57,000 (3)	42,000 (3)	12
	0.250 to 0.749	60,000 (3)	44,000 (3)	12
	0.750 to 1.499	65,000 (3)	46,000 (3)	10
	1.500 and over (4)	70,000 (3)	52,000 (3)	10
Tubing				
24S-O	All	35,000 (2)	....	..
24S-T	*Diameter ¼" to 2"* Wall thickness:			
	0.018–0.024	64,000	42,000 (3)	10
	0.025–0.049	64,000	42,000 (3)	12
	0.050–0.259	64,000	42,000 (3)	14
	0.260–0.500	64,000	42,000 (3)	16
	Diameter greater than 2" to 8" Wall thickness:			
	0.025–0.259	64,000	42,000 (3)	10
	0.260–0.500	64,000	42,000 (3)	12

[1] See page 88 for definitions and significance of terms; also additional data.

[2] Maximum. So specified to insure complete annealing.

[3] Flat sheet in 24S and Alclad 24S heat treated by the user cannot be required to have higher tensile and yield strengths than those shown for coiled sheet in the respective thickness ranges. Alclad sheet and plate in thicknesses 0.064 inch and greater have thinner surface coatings than sheet in thicknesses less than 0.064 inch. Tubing heat treated by the user may have a minimum yield strength of 40,000 pounds per square inch and extruded shapes, minimum tensile and yield strengths of 57,000 and 38,000 pounds per square inch, respectively. The flattening and straightening operations performed on these products as supplied in the heat-treated temper (T) make it possible to specify the higher properties.

[4] Up to a maximum cross-sectional area of 25 square inches.

TABLE 23

Mechanical Properties Specifications—53S Alloy Products[1]

Material	Dimensions, Inches	Tensile Strength, Lb./Sq. In. Minimum Except for 53S-O[2]	Yield Strength[1] (Set = 0.2%), Lb./Sq. In. Minimum	Elongation Per Cent in 2 Inches or in 4D[1], Minimum
Wire, Rod, Bar and Shapes				
53S-O				
Wire	Up to 0.124	19,000 (2)	....	..
Rounds, squares, hexagons, octagons, and rectangles	0.125–3.000	19,000 (2)	....	20
Shapes	All	19,000 (2)	....	18
53S-W				
Wire	Up to 0.124	25,000	....	..
Rounds, squares, hexagons, octagons, and rectangles	0.125–3.000	25,000	14,000	18
Shapes	All	25,000	14,000	16
53S-T				
Wire	Up to 0.124	32,000	....	..
Rounds, squares, hexagons, octagons, and rectangles	0.125–3.000	32,000	25,000	14
Shapes	All	32,000	25,000	10
53S-T5				
Shapes (extruded)	All	22,000	16,000	10
53S-T61				
Wire	Up to 0.124	30,000	....	..
Tubing				
53S-O	All	19,000 (2)	......	..
53S-W	*Diameter ¼" to 2"* Wall thickness:			
	0.025–0.049	28,000	14,000	16
	0.050–0.259	28,000	14,000	18
	0.260–0.500	28,000	14,000	20
	Diameter greater than 2" to 8" Wall thickness:			
	0.025–0.049	28,000	14,000	14
	0.050–0.259	28,000	14,000	16
	0.260–0.500	28,000	14,000	18
53S-T	*Diameter ¼" to 2"* Wall thickness:			
	0.025–0.049	35,000	28,000	12
	0.050–0.259	35,000	28,000	14
	0.260–0.500	35,000	28,000	16
	Diameter greater than 2" to 8" Wall thickness:			
	0.025–0.049	35,000	28,000	8
	0.050–0.259	35,000	28,000	10
	0.260–0.500	35,000	28,000	12

[1] See page 88 for definitions and significance of terms; also additional data. For forgings see Table 18.
[2] Maximum. So specified to insure complete annealing.

TABLE 24

Mechanical Properties Specifications—75S Alloy Products[1]

Material	Dimensions, Inches	Tensile Strength, Lb./Sq. In. Minimum Except for 75S-O[2]	Yield Strength[1] (Set = 0.2%), Lb./Sq. In. Minimum	Elongation Per Cent in 2 Inches or in 4D[1], Minimum
Sheet and Plate				
75S-O	0.016–0.500	40,000 (2)	....	10
75S-T	0.016–0.039	76,000	65,000	7
	0.040–0.249	77,000	66,000	8
	0.250–0.500	77,000	66,000	8
	0.501–1.000	77,000	66,000	6
	1.001–2.000	77,000	66,000	4
Alclad 75S-O	0.016–0.500	36,000 (2)	....	10
Alclad 75S-T	0.016–0.039	70,000	60,000	7
	0.040–0.249	72,000	62,000	8
	0.250–0.499	72,000	62,000	8
	0.500–1.000	77,000	66,000	6
	1.001–2.000	77,000	66,000	4
Extruded Shapes				
75S-O	All	40,000 (2)	....	6
75S-T	Up to 0.250	78,000	70,000	6
	0.251–4.000 (3)	80,000	70,000	6
Rolled Rod and Bar				
75S-T	Up to 3.000	77,000	66,000	6

[1] See page 88 for definitions and significance of terms, and Table 12 for typical properties.

[2] Maximum. So specified to insure complete annealing.

[3] The properties apply to sections having a cross-sectional area not over 20 square inches.

TABLE 25

Mechanical Properties Specifications—61S Alloy Products[1]

Material	Dimensions,[1] Inches	Tensile Strength, Lb./Sq. In. Minimum Except for 61S-O[2]	Yield Strength[1] (Set=0.2%), Lb./Sq. In. Minimum	Elongation Per Cent in 2 Inches or in 4D[1], Minimum
Sheet and Plate				
61S-O	0.010–0.020	22,000 (2)	......	14
	0.021–0.128	22,000 (2)	......	16
	0.129–0.500	22,000 (2)	......	18
61S-W	0.010–0.020	30,000	16,000	14
	0.021–0.249	30,000	16,000	16
	0.250–0.500	30,000	16,000	18
61S-T	0.010–0.020	42,000	35,000	8
	0.021–0.249	42,000	35,000	10
	0.250–0.500	42,000	35,000	10
Wire, Rod, Bar and Shapes				
61S-O Wire	Up to 0.124	22,000 (2)	......	..
61S-O (Rolled)	0.125 to 3.000	22,000 (2)	......	18
61S-O Shapes	All Sizes	22,000 (2)	......	16
61S-W Wire	Up to 0.124	30,000	......	..
61S-W Rounds, Squares, Hexagons, Octagons	0.125 to 3.000	30,000	14,000	18
61S-W Rectangles	Up to 3 x 10	30,000	14,000	18
61S-W Shapes	All Sizes	26,000	16,000	16
61S-T Wire	Up to 0.124	42,000	......	..
61S-T Rounds, Squares, Hexagons, Octagons	0.125 to 3.000	42,000	35,000	10
61S-T Rectangles	Up to 3 x 10	42,000	35,000	10
61S-T Shapes	All Sizes	38,000	35,000	10
Tubing				
61S-O	All sizes	22,000 (2)	......	..
61S-W	*Diameter ¼″ to 2″* Wall thickness:			
	0.025–0.049	30,000	16,000	16
	0.050–0.259	30,000	16,000	18
	0.260–0.500	30,000	16,000	20
	Diameter greater than 2″ to 8″ Wall thickness:			
	0.025–0.049	30,000	16,000	14
	0.050–0.259	30,000	16,000	16
	0.260–0.500	30,000	16,000	18
61S-T	*Diameter ¼″ to 2″* Wall thickness:			
	0.025–0.049	42,000	35,000	10
	0.050–0.259	42,000	35,000	12
	0.260–0.500	42,000	35,000	14
	Diameter greater than 2″ to 8″ Wall thickness:			
	0.025–0.049	42,000	35,000	8
	0.050–0.259	42,000	35,000	10
	0.260–0.500	42,000	35,000	12

[1] See page 88 for definitions and significance of terms; also additional data.
[2] Maximum. So specified to insure complete annealing.

TABLE 26

Commercial Thickness Tolerances for Flat and Coiled Sheet and Plate

(*Plus or Minus*)

ALLOYS 2S AND 3S[1]

Thickness, Inches	Width						
	Up to 18″, incl.	Over 18″ through 36″	Over 36″ through 54″	Over 54″ through 72″	Over 72″ through 90″	Over 90″ through 102″	Over 102″ through 132″
3.000 to 2.751	0.090	0.090	0.090	0.090	0.120	0.150	.....
2.750 to 2.251	0.075	0.075	0.075	0.075	0.100	0.125	0.125
2.250 to 1.876	0.060	0.060	0.060	0.060	0.080	0.100	0.100
1.875 to 1.626	0.052	0.052	0.052	0.052	0.070	0.088	0.088
1.625 to 1.376	0.045	0.045	0.045	0.045	0.060	0.075	0.075
1.375 to 1.126	0.040	0.040	0.040	0.040	0.052	0.065	0.065
1.125 to 0.876	0.035	0.035	0.035	0.035	0.045	0.055	0.055
0.875 to 0.626	0.030	0.030	0.030	0.030	0.037	0.045	0.045
0.625 to 0.439	0.025	0.025	0.025	0.025	0.030	0.035	0.035
0.438 to 0.321	0.019	0.019	0.019	0.019	0.023	0.026	0.026
0.320 to 0.250	0.013	0.013	0.013	0.015	0.017	0.020	.....
0.249 to 0.204	0.009	0.009	0.011	0.013	0.015	0.017	.....
0.203 to 0.173	0.007	0.007	0.009	0.011	0.013	0.015	.....
0.172 to 0.141	0.006	0.006	0.008	0.009	0.011	0.012	.....
0.140 to 0.109	0.0045	0.0045	0.005	0.007	0.009	0.010	.....
0.108 to 0.097	0.0035	0.004	0.005	0.007	0.009	0.010	.....
0.096 to 0.077	0.003	0.003	0.004	0.006	0.008	.....	.....
0.076 to 0.069	0.0025	0.003	0.004	0.006	0.008	.....	.....
0.068 to 0.046	0.0025	0.003	0.004	0.005	0.007	.....	.....
0.045 to 0.037	0.002	0.0025	0.003	0.004	.....	.....	.....
0.036 to 0.029	0.002	0.002	0.0025	0.0035	.....	.....	.....
0.028 to 0.018	0.0015	0.002	0.0025	.....	.....	.....	.....
0.017 to 0.011	0.0015	0.0015	0.002	.....	.....	.....	.....
0.010 to 0.008	0.001	0.0015	.....	.....	.....	.....	.....
0.007 to 0.006	0.001	0.001	.....	.....	.....	.....	.....

[1] See page 120 for tolerances on sheet and plate of Alclad 14S, 24S, Alclad 24S, 52S, 61S, 75S and Alclad 75S.

TABLE 26—*Concluded*

Commercial Thickness Tolerances for Flat and Coiled Sheet and Plate

(*Plus or Minus*)

ALLOYS ALCLAD 14S, 24S, ALCLAD 24S, 52S, 61S, 75S AND ALCLAD 75S.
Applies only to commercial sizes,[1] tolerances for other sizes subject to special inquiry.

Thickness, Inches	Width											
	Up to 18″, incl.	Over 18″ thru 36″	Over 36″ thru 48″	Over 48″ thru 54″	Over 54″ thru 60″	Over 60″ thru 66″	Over 66″ thru 72″	Over 72″ thru 78″	Over 78″ thru 84″	Over 84″ thru 90″	Over 90″ thru 96″	Over 96″ thru 120″
3.000 to 2.751	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.120	0.120	.....	.....	.....
2.750 to 2.251	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.100	0.100	0.100	.....	.....
2.250 to 1.876	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.080	0.080	0.080	0.100	0.100
1.875 to 1.626	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.070	0.070	0.070	0.088	0.088
1.625 to 1.376	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.060	0.060	0.060	0.075	0.075
1.375 to 1.126	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.052	0.052	0.052	0.065	0.065
1.125 to 0.876	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.045	0.045	0.045	0.055	0.055
0.875 to 0.626	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.037	0.037	0.037	0.045	0.045
0.625 to 0.439	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.035	0.035
0.438 to 0.321	0.019	0.019	0.019	0.019	0.020	0.020	0.023	0.023	0.025	0.025	0.026	.....
0.320 to 0.250	0.013	0.013	0.013	0.013	0.015	0.018	0.020	0.020	0.020	0.020	.....	.....
0.249 to 0.204	0.009	0.009	0.011	0.011	0.013	0.016	0.018	0.018	0.018	0.018	0.024	0.028
0.203 to 0.173	0.007	0.007	0.010	0.010	0.011	0.014	0.016	0.017	0.017	0.017	0.022	0.026
0.172 to 0.141	0.006	0.006	0.008	0.008	0.009	0.012	0.014	0.015	0.016	0.017	0.019	0.023
0.140 to 0.109	0.0045	0.0045	0.005	0.005	0.007	0.010	0.012	0.013	0.014	0.016	0.018	0.020
0.108 to 0.097	0.004	0.004	0.005	0.005	0.007	0.010	0.012	0.013	0.014	0.016	0.018	0.020
0.096 to 0.077	0.0035	0.0035	0.004	0.005	0.006	0.008	0.010	0.010	0.011	0.012	.....	.....
0.076 to 0.069	0.003	0.003	0.004	0.005	0.006	0.008	0.010	0.010	0.011	0.012	.....	.....
0.068 to 0.046	0.0025	0.003	0.004	0.005	0.006	0.006	0.007	0.008	0.009	.....	.....	.....
0.045 to 0.037	0.002	0.0025	0.003	0.004	0.005	.....	.....	.....	.....	.....	.....	.....
0.036 to 0.029	0.002	0.002	0.0025	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.028 to 0.018	0.0015	0.002	0.0025	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.017 to 0.011	0.0015	0.0015	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.010 to 0.007	0.001	0.0015	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[1] See Tables 38 through 44 for commercial sizes of sheet and Tables 46 through 48 for commercial sizes of plate.

TABLE 27

Commercial Tolerances for Sheet and Plate, All Alloys

(*Width, Length, Diameter*)

FLAT SHEET—SHEARED

Width Tolerance (Plus or Minus), Inch

Thickness, Inch	Widths 1/4" through 4"	Widths over 4" through 18"	Widths over 18" through 36"	Widths over 36" through 54"	Widths over 54" through 72"	Widths over 72" through 102"
0.249 to 0.103	..	3/32 (2)	1/8	3/16	3/16	1/4
0.102 to 0.006	1/32 (1)	1/16	3/32	1/8	5/32	3/16

Length Tolerance (Plus or Minus), Inch

Thickness, Inch	Lengths through 18"	Lengths over 18" through 48"	Lengths over 48" through 120"	Lengths over 120" through 180"	Lengths over 180" through 540"
0.249–0.006	1/16	3/32	1/8	5/32	1/4

[1]For widths of 4 inches or less the maximum thickness of flat sheet which can be sheared commercially is 0.093 inch. Thicker sheet is sawed.

[2]For flat sheet in thicknesses of 0.201 inch to 0.249 inch the minimum width which can be sheared is 5 inches. Narrower widths must be sawed.

COILED SHEET—SHEARED

Width Tolerance (Plus or Minus), Inch

Thickness, Inch	Widths 1/4" through 6"	Widths over 6" through 12"	Widths over 12" through 24"
0.102 to 0.006	0.010	0.016	1/32

SHEET AND PLATE CIRCLES—SHEARED

Diameter Tolerance (Plus or Minus), Inch

Thickness, Inch	Diameters 5" through 18"	Diameters over 18" through 36"	Diameters over 36" through 96"
0.625 to 0.376	..	1/8	3/16
0.375 to 0.250	..	1/16	1/8
0.249 to 0.006	1/32	3/64	3/64

TABLE 27—*Concluded*

Commercial Tolerances for Sheet and Plate, All Alloys

(***Width, Length, Diameter***)

SHEET AND PLATE—SAWED

Dimension Tolerance (Plus or Minus), Inch

Thickness, Inches	Dimensions through 10″	Dimensions over 10″ through 36″	Dimensions over 36″ through 60″	Dimensions over 60″ through 130″
Up to 3	1/32	1/16	3/32	3/32

PLATE—SHEARED

Width and Length Tolerance (Plus only), Inch

Thickness,[1] Inch	Width Tolerance[1]	Length Tolerance		
		Lengths through 12 ft.	Lengths over 12 ft. through 20 ft.	Lengths over 20 ft. through 45 ft.
1.000 to 0.501	1/2	1/2	9/16	5/8
0.500 to 0.250	3/8	3/8	7/16	1/2

[1] For limits for shearing plate see Note 2 to Tables 45 to 48.

TABLE 28

Commercial Tolerances of Rolled Structural Shapes

(*Applicable to Sizes and Sections Included in Table 51*)

Dimensions	Tolerance
Thickness of section.	Plus or minus 2½ per cent of nominal thickness—minimum tolerance: ±0.010 inch.
Over-all dimensions. Length of leg of angles or zees.	Plus or minus 2½ per cent of nominal—minimum tolerance: ±1/16 inch.
Length Up to 20 feet, not inclusive. 20 feet to 30 feet, inclusive. Over 30 feet.	 Minus 0, Plus ¼ inch. Minus 0, Plus ⅜ inch. Minus 0, Plus ½ inch.
Channels, over-all width.	Plus 3/32 inch, minus 1/16 inch.
Channels, width of flange.	Plus or minus 4 per cent of nominal width.
Weight of a lot or shipment of sizes 3 inches or larger.	Plus or minus 2½ per cent of nominal weight.[1]

[1] Actual weight shipped is invoiced. For sizes smaller than 3 inches, dimension tolerances only apply.

TABLE 29

Commercial Tolerances for Wire, Rod and Bar

ROLLED ROUND ROD (ALL ALLOYS)

Diameter, Inches	Tolerance, Inch		Diameter, Inches	Tolerance, Inch	
	Plus	Minus		Plus	Minus
1.501 to 2.000	0.006	0.006	3.500 to 5.000	1/32	1/64
2.001 to 3.499	0.008	0.008	5.001 to 8.000	1/16	1/32

ROLLED BAR (ALL ALLOYS)
(Squares, Hexagons,[1] Rectangles)

Least Distance Across Flats, Inches	Tolerance, Inch Plus or Minus	Width (of Rectangles), Inches	Tolerance, Inch Plus or Minus
up to 0.500	0.006	up to 1.500	1/64
0.501 to 0.750	0.008	1.501 to 4.000	1/32
0.751 to 1.000	0.012	4.001 to 6.000	3/64
1.001 to 2.000	0.016	6.001 to 10.000	1/16
2.001 to 3.000	0.020		

[1] Available only in sizes greater than 1.5 inches; smaller sizes cold-finished.

COLD-FINISHED WIRE, ROD AND BAR (ALL ALLOYS)
Rounds, Squares, Hexagons. Octagons. Rectangles up to 1½ inches thick or to 4 inches wide

Diameter or Distance Across Flats, Inches	Tolerance, Inch Plus or Minus		
	Rounds	Squares Hexagons Octagons	Rectangles
up to 0.035	0.0005	......	......
0.036 to 0.064	0.001	0.0015	0.0015
0.065 to 0.500	0.0015	0.002	0.002
0.501 to 1.000	0.002	0.0025	0.0025
1.001 to 1.500	0.0025	0.003	0.003
1.501 to 2.000	0.004	0.005	0.005
2.001 to 3.000	0.004	......	0.005
3.001 to 4.000	......	......	0.005

TABLE 29—*Concluded*

Commercial Tolerances for Wire, Rod and Bar

CENTERLESS GROUND WIRE AND ROD, ROUND (ALL ALLOYS)

Diameter, Inches	Tolerance, Inch Plus or Minus
0.0625 to 0.625	0.0005
0.626 to 1.500	0.001
1.501 to 2.500	0.005

TABLE 30

Commercial Tolerances of Rough-Rolled, Round-Cornered Squares and Rectangles—All Alloys

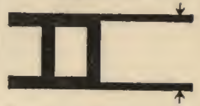
Size		Tolerance, Inch	
Thickness, Inches	Width, Inches	Thickness, Plus or Minus	Width, Plus or Minus
2 to 2.99 by	10⅛ to 16	1/32	¼
3 to 5.99 by	4 to 16	1/16	¼
6 to 8.00 by	6 to 12	1/16	¼

TABLE 31

Commercial Tolerances of Flattened Wire and Flattened and Slit Wire—All Alloys

FLATTENED WIRE (Round Edges)				FLATTENED AND SLIT WIRE (Slit Edges)			
Dimensions	Commercial Sizes, Inches		Tolerance, Inch Plus or Minus	Dimensions	Commercial Sizes, Inches		Tolerance, Inch Plus or Minus
	Minimum	Maximum			Minimum	Maximum	
Thicknesses	0.010	0.020	0.001	Thicknesses	0.010	0.020	0.001
	0.021	0.060	0.0015		0.021	0.060	0.0015
	0.061	0.187	0.002		0.061	0.080	0.002
Widths	0.030	0.875	0.007	Widths	0.125	0.625	0.0025
	0.876	2.000	0.010		0.626	1.500	0.004
					1.501	5.000	0.006

TABLE 32
Commercial Tolerances for Extruded Rods, Bars and Shapes
CROSS-SECTIONAL DIMENSIONS

Specified dimension, inches	Tolerance,[1] inch				
	Allowable deviation from specified dimension where 75 per cent or more of the dimension is metal		Allowable deviation from specified dimension where over 25 per cent of the dimension is space		
				Where the space is not completely enclosed	
	Rod and bar only	Shapes[2] 	Where the space is completely enclosed 	Where metal on both sides is ⅛ inch thick or more, and projects less than 2 inches 	Where metal on either side is less than ⅛ inch thick, or projects 2 inches or more 
Over 10 through 12	±0.065	±0.065	±0.080	±0.080	±0.160
Over 8 through 10	±0.055	±0.055	±0.065	±0.065	±0.130
Over 6 through 8	±0.045	±0.045	±0.055	±0.055	±0.110
Over 4 through 6	±0.035	±0.035	±0.045	±0.045	±0.090
Over 2 through 4	±0.015	±0.025	±0.035	±0.035	±0.070
Over 1.5 through 2	±0.012	±0.020	±0.025	±0.025	±0.050
Over 1 through 1.5	±0.012	±0.017	±0.025	±0.025	±0.050
Over 0.750 through 1	±0.010	±0.014	±0.020	±0.020	±0.040
Over 0.500 through 0.750	±0.010	±0.012	±0.020	±0.020	±0.040
Over 0.375 through 0.500	±0.007	±0.010	±0.015	±0.015	±0.030
Over 0.250 through 0.375	±0.007	±0.009	±0.015	±0.015	±0.030
Over 0.125 through 0.250	±0.007	±0.008	±0.015	±0.015	±0.030
Over 0.063 through 0.125	±0.007	±0.007	±0.010	±0.010	±0.020
0.063 and under	±0.006	±0.006	±0.010	±0.010	±0.020

[1] The sum of the tolerances of component dimensions will not be used as a tolerance for an over-all dimension.

[2] For hollow shapes in which the area of the opening is 0.1105 square inch or more, the tolerance on the wall thickness is ±10% of the specified thickness; when the opening is of smaller size, the tolerance is ±20%. The minimum tolerance is ±0.010 inch and the maximum ±0.060 inch.

TABLE 32—*Continued*

Commercial Tolerances for Extruded Rods, Bars and Shapes

ANGLES

Minimum specified leg thickness, inch	Tolerance, degrees
	 Allowable deviation from specified angle
0.188 and over	±1½
Under 0.188	±2

FLAT SURFACES

Allowable deviation from flat, 0.004 inch per inch of width; 0.004 inch minimum.

CORNER AND FILLET RADII

Specified radius, inch	Tolerance, inch
	Allowable deviation from specified radius
0.188 and over	±10%
Under 0.188	±1/64
Sharp corners	+1/64

CURVED SURFACES

Chord of curved surface, inches	Tolerance, inch
	Allowable deviation from specified contour
5 and over	±0.030
3 to (not incl.) 5	±0.020
1½ to (not incl.) 3	±0.012
Under 1½	±0.006

STRAIGHTNESS

Circumscribed circle diameter,[1] inches	Minimum thickness, inch	Tolerance,[2] inch
		Allowable deviation from straight per foot of length
1½ and over	....	0.0125
Under 1½	Over 0.094	0.0125
Under 1½	0.094 or under	0.050[3]

[1] The circumscribed circle diameter is the diameter of the smallest circle that will completely enclose the shape.

[2] Not applicable to extruded shapes in the annealed (O) temper.

[3] When weight of shape on flat surface minimizes deviation.

TABLE 32—*Concluded*

Commercial Tolerances for Extruded Rods, Bars and Shapes

TWIST

Circumscribed circle diameter,[1] inches	Tolerance,[2] degrees — Allowable deviation from straight: In each foot of length	Tolerance,[2] degrees — Allowable deviation from straight: In total length of piece
3 and over	¼°	Length, ft., times ¼° not over 3°
1½ to (not incl.) 3	½°	Length, ft., times ½° not over 5°
Under 1½	1°	Length, ft., times 1°

[1] The circumscribed circle diameter is the diameter of the smallest circle that will completely enclose the shape.

[2] Not applicable to extruded shapes in the annealed (O) temper.

LENGTH

Specified length, feet	Tolerance, inch — Allowable deviation from specified length
30 and over	+½
10 to (not incl.) 30	+¼
Under 10	+⅛

SQUARENESS OF CUT ENDS

1 Degree

TABLE 33

Commercial Tolerances for Drawn Tubing

ROUND TUBING, DIAMETER TOLERANCE

Nominal Diameter, Inches	Tolerance, Inch (Plus or Minus)		
	Mean Diameter[1] or Pi-Tape Measurement—3S, 24S, 52S, 61S	Individual Measurement of Diameter (Out-of-Roundness) Except (1) Soft (O), or (2) thin wall tubes[2]	
		3S, 52S	24S, 61S
⅛ to ½ incl.	0.003	0.003	0.006
Greater than ½ to 1 incl.	0.004	0.004	0.008
Greater than 1 to 2 incl.	0.005	0.005	0.010
Greater than 2 to 3 incl.	0.006	0.006	0.012
Greater than 3 to 5 incl.	0.008	0.008	0.016
Greater than 5 to 6 incl.	0.010	0.010	0.020
Greater than 6 to 8 incl.	0.015	0.015	0.030
Greater than 8 to 10 incl.	0.020	0.020	0.040
Greater than 10 to 12 incl.	0.025	0.025	0.050

[1] Mean diameter is the average of any two measurements of diameter taken at right angles to each other at any point along the length of the tube.

[2] Thin wall tubes, i.e. tubes having a wall thickness less than 2.5 per cent of the diameter or less than 0.020 inch, and tubes in the soft (O) temper shall be commercially round. The deviations of individual measurements from the nominal will vary with the alloy and the ratio of wall thickness to diameter.

ROUND TUBING, WALL THICKNESS TOLERANCE

Nominal Wall Thickness (T), Inch	Tolerance, Inch (Plus or Minus)		
	Mean Wall Thickness[1]	Individual Measurements of Wall Thickness	
	24S, 61S	24S, 61S	3S, 52S
0.010 to 0.035	0.002	10% of T	0.002
0.036 to 0.049	0.003	10% of T	0.003
0.050 to 0.120	0.004	10% of T	0.004
0.121 to 0.203	0.005	10% of T	0.005
0.204 to 0.300	0.008	10% of T	0.008
0.301 to 0.375	0.012	10% of T	0.012
0.376 to 0.500	0.032	10% of T	0.032

[1] Mean wall thickness is the average of the two measurements taken at opposite ends of any diameter of the tube.

TABLE 33—*Concluded*

Commercial Tolerances for Drawn Tubing

ROUND TUBING AND PIPE, LENGTH TOLERANCES—ALL ALLOYS

Nominal Diameter, Inches	Tolerance, Inch (Plus only)				
	Lengths 2′ or Less	Lengths over 2′ to 20′	Lengths over 20′ to 30′	Lengths over 30′	Coiled Tubing
To 1/4 incl.	1/8	1/4	3/8	1/2	3%
Greater than 1/4 to 2 incl.	1/16	1/8	3/16	3/8	2%
Greater than 2 to 3 incl.	1/8	3/16	1/4	5/16	...
Greater than 3 to 10 incl.	3/16	1/4	5/16	3/8	...
Greater than 10 to 12 incl.	1/4	5/16	3/8	..	...

A tolerance of 1/64″ per inch of O. D., or fraction thereof, will apply on the squareness of all saw cuts.

ROUND TUBING AND PIPE, STRAIGHTNESS TOLERANCE—ALL ALLOYS, ALL TEMPERS EXCEPT SOFT[1]

Outside Diameters,[1] Inches	Tolerance
3/8 to 12	0.1 inch in 10 feet or one part in 1200 parts of length.

[1] Tubing in the soft temper or in diameters less than 3/8 inch is supplied commercially straight, substantially free from kinks and short bends.

PIPE—STANDARD AND EXTRA HEAVY I. P. S.—3S[1]

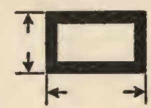
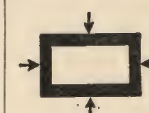
Size, Inches	O. D. Tolerance, Inch (Plus only)	I. D. Tolerance, Inch (Minus only)
1/8 to 1/2 incl.	0.005	0.003
Greater than 1/2 to 2 incl.	0.008	0.005
Greater than 2 to 4 incl.	0.010	0.007
Greater than 4 to 6 incl.	0.012	0.008
Greater than 6 to 8 incl.	0.014	0.009
Greater than 8 to 10 incl.	0.016	0.012

[1] Tolerances for 24S and 61S pipe are the same as those for round tubing of these alloys.

TABLE 34

Commercial Tolerances for Extruded Tubing

OUTSIDE DIAMETER OR WIDTH

ROUND TUBING			SQUARE, RECTANGULAR, HEXAGONAL AND OCTAGONAL TUBING			
Specified outside diameter, inches	Tolerance, inch		Specified width or depth, inches	Tolerance, inch	Specified width or depth at right angles to width or depth being measured, inches	Tolerance, inch
	Allowable deviation of mean diameter[1] from specified diameter 	Allowable deviation of diameter at any point from specified diameter[2] 		Square and rectangular: Allowable deviation of width or depth at corners from specified width or depth 		Square, rectangular, hexagonal and octagonal: Allowable deviation of width or depth not at corners from specified width or depth 
12 and over	On application	On application				
10 to (not incl.) 12	±0.055	±0.125				
8 to (not incl.) 10	±0.045	±0.100				
6 to (not incl.) 8	±0.037	±0.075				
4 to (not incl.) 6	±0.025	±0.050	4 to and incl. 5	±0.025	4 to and incl. 5	±0.050
2 to (not incl.) 4	±0.015	±0.030	2 to (not incl.) 4	±0.015	2 to (not incl.) 4	±0.030
1¼ to (not incl.) 2	±0.012	±0.025	1¼ to (not incl.) 2	±0.012	1¼ to (not incl.) 2	±0.025

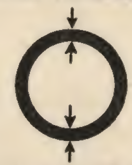
[1] The "mean diameter" is determined by the average of two measurements taken at right angles to each other.

[2] Not applicable in the annealed (O) temper or if wall thickness is less than 2½ per cent of the outside diameter.

TABLE 34—*Continued*

Commercial Tolerances for Extruded Tubing

WALL THICKNESS

ROUND TUBING					SQUARE, RECTANGULAR, HEXAGONAL AND OCTAGONAL TUBING	
Specified thickness, inches	Tolerance,[1] inch: Allowable deviation of mean wall thickness[2] from specified wall thickness 			Tolerance,[1] inch: Allowable deviation of wall thickness at any point from mean wall thickness[2] (Eccentricity)	Specified thickness, inches	Tolerance, inch: Allowable deviation of wall thickness at any point from specified wall thickness 
	1¼" O.D. to (not incl.) 3" O.D.	3" O.D. to (not incl.) 5" O.D.	5" O.D. and over			
1.5 and over	....	On application		Plus or minus 10% of mean wall thickness; max. ±0.060 min. ±0.010	1.5 and over	On application
1.0 to (not incl.) 1.5	....	±0.045	±0.065		1.0 to (not incl.) 1.5	±0.045
0.750 to (not incl.) 1.0	....	±0.035	±0.055		0.750 to (not incl.) 1.0	±0.035
0.500 to (not incl.) 0.750	±0.020	±0.028	±0.045		0.500 to (not incl.) 0.750	±0.020
0.375 to (not incl.) 0.500	±0.015	±0.021	±0.035		0.375 to (not incl.) 0.500	±0.015
0.250 to (not incl.) 0.375	±0.011	±0.016	±0.025		0.250 to (not incl.) 0.375	±0.011
0.125 to (not incl.) 0.250	±0.009	±0.013	±0.020		0.125 to (not incl.) 0.250	±0.009
0.063 to (not incl.) 0.125	±0.008	±0.010	±0.015		0.063 to (not incl.) 0.125	±0.008
Under 0.063	±0.007	±0.008	±0.010		Under 0.063	±0.007

[1] If the extruded tubing is to be drawn into drawn tubing, allowance for wall thickness tolerances greater than standard is recommended in the case of alloys other than 2S or 3S.

[2] The "mean wall thickness" is determined by the average of two measurements taken at 180 degrees from each other.

TABLE 34—*Concluded*

Commercial Tolerances for Extruded Tubing

CORNER AND FILLET RADII

Specified radius, inch	Tolerance, inch
	Allowable deviation from specified radius
0.188 and over	±10%
Under 0.188	±1/64
Sharp corners	+1/64

STRAIGHTNESS

0.010 inch per foot of length[1]

TWIST

Specified width or depth (whichever greater), inches	Tolerance,[1] degrees	
	Allowable deviation from straight	
	In each foot of length	In total length of piece
3 and over	¼°	Length, ft., times ¼° not over 3°
1½ to (not incl.) 3	½°	Length, ft., times ½° not over 5°
Under 1½	1°	Length, ft., times 1°

[1] Not applicable in the annealed (O) temper.

LENGTH

Specified length, feet	Tolerance, inch
	Allowable deviation from specified length
30 and over	+½
10 to (not incl.) 30	+¼
Under 10	+⅛

SQUARENESS OF CUT ENDS

1 Degree

TABLE 35

Flat Sheet and Plate

Alcoa Standard Sizes

Thickness, Inch	2S-O	2S-½H	3S-O	3S-½H	52S-O	52S-¼H	52S-½H
0.012	24x72	24x 72	......	......	......	......	......
0.016	24x72	24x 72	24x72	24x 72	......	......	......
0.020	24x72	24x 72	24x72	24x 72	36x 96	36x 96	36x 96
0.025	24x72	24x 72 36x 96	24x72	24x 72	36x 96	36x 96	36x 96 ......
0.032	24x72 36x96	24x 72 36x 96 48x144	24x72 36x96	36x 96 48x144	48x144	36x 96 48x144	48x144 ....
0.040	24x72 36x96	24x 72 36x 96 48x144	24x72 36x96	36x 96 48x144	48x144	36x 96 48x144	48x144 ....
0.051	24x72 36x96	24x 72 36x 96 48x144	24x72 36x96	36x 96 48x144	48x144	36x 96 48x144	48x144 ....
0.064	24x72 36x96	24x 72 36x 96 48x144	24x72 36x96	36x 96 48x144	48x144	36x 96 48x144	48x144 ....
0.081	24x72 36x96	24x 72 36x 96 48x144	24x72 36x96	36x 96 48x144	48x144	36x 96 48x144	48x144 ....
0.091	24x72 36x96	24x 72 36x 96 48x144	24x72 36x96	36x 96 48x144	48x144	36x 96 48x144	48x144 ....
0.102	24x96 36x72	24x 72 36x 96 48x144	24x72 36x96	36x 96 48x144	48x144	36x 96 48x144	48x144 ....
0.125	24x72 36x96	24x 72 36x 96 48x144	24x72 36x96	36x 96 48x144	48x144	36x 96 48x144	48x144 ....
0.156	....	....	....	....	48x144	36x 96 48x144	48x144 ......
0.188	....	24x 72 36x 96 48x144	....	36x 96 48x144	48x144	36x 96 48x144	48x144 ....
0.250	....	....	....	36x 96[1] 48x144[1]	....	....	48x144[1] ......

[1] Indicates "As-Rolled" Temper.

TABLE 35—*Concluded*

Flat Sheet and Plate

Alcoa Standard Sizes

Thickness, Inch	61S-T	24S O and T	Alclad 24S O and T	Alclad 75S O and T
0.012	....	....	24 x 120	....
0.016	....	....	36 x 144	36 x 144
0.020	....	36 x 144	36 x 144	36 x 144
0.025	36 x 144	48 x 144	48 x 144	36 x 144
0.032	48 x 144	48 x 144	48 x 144	48 x 144
0.040	48 x 144	48 x 144	48 x 144	48 x 144
0.051	48 x 144	48 x 144	48 x 144	48 x 144
0.064	48 x 144	48 x 144	48 x 144	48 x 144
0.072	48 x 144	48 x 144	48 x 144	48 x 144
0.081	48 x 144	48 x 144	48 x 144	48 x 144
0.091	48 x 144	48 x 144	48 x 144	48 x 144
0.102	48 x 144	48 x 144	48 x 144	48 x 144
0.125	48 x 144	48 x 144	48 x 144	48 x 144
0.156	48 x 144	48 x 144	48 x 144	48 x 144
0.188	48 x 144	48 x 144	48 x 144	48 x 144
0.250	48 x 144	48 x 144	48 x 144	....

TABLE 36

Commercial Sizes of Flat Sheet[1] 2S and 3S

Thickness, Inch	Standard[2] Width, Inches	Maximum Rolling Limits[4]		Maximum Stretcher Limits	
		Width, Inches	Length, Feet	Width, Inches	Length, Feet
0.249–0.172	48	102	30	90	(3)
0.171–0.136	48	102	30	90	(3)
0.135–0.096	48	102	30	88	(3)
0.095–0.068	48	90	30	86	(3)
0.067–0.061	48	84	24	86	(3)
0.060–0.043	48	84 76 60	16 20 30	76	20
0.042–0.038	48	76 66 60	16 20 30	(3)	20
0.037–0.030	48	66 60	14 20	(3)	(3)
0.029–0.019	36	60 54	10 16	(3)	(3)
0.018–0.015	36	48	12	(3)	(3)
0.014–0.012	24	42	12	(3)	(3)
0.011–0.0095	24	36	12	(3)	(3)
0.009–0.0075	24	30	8	(3)	(3)
0.007–0.006	18	24	8	(3)	(3)

[1] Available in tempers O to H with the following limitations: maximum thickness for H temper, 0.128 inch; for ¾H temper, 0.162 inch. Minimum thickness for ¼H temper, 0.017 inch; for ½H temper, 0.0095 inch.

[2] Refer to Table 35, page 133, for Alcoa Standard Sizes.

[3] Greater than rolling limits.

[4] Maximum diameter of circle same as maximum width of sheared sheet, except circles larger than 96 inches in diameter are sawed.

TABLE 37

Commercial Widths of Coiled Sheet 2S and 3S

MILL FINISH AND ONE SIDE BRIGHT MILL FINISH

Thickness, Inch	Mill Finish	One Side Bright Mill Finish	Available Tempers
	Maximum Rolling Limit,[1] Inches	Maximum Rolling Limit,[1] Inches	
0.102–0.086	36	. .	O, ¼H.[2] H
0.085–0.054	36	26	O, ¼H,[2] ½H, H
0.053–0.038	36	26	O, ¼H,[2] ½H, ¾H, H
0.037–0.030	36	24	O, ¼H,[2] ½H, ¾H, H
0.029–0.024	36	24	O, ¼H,[2] ½H, ¾H, H
0.023–0.019	36	24	O, ¼H,[2] ½H, ¾H, H
0.018–0.017	36	24	O, ¼H,[2] ½H, ¾H, H
0.016–0.015	36	24	O, ½H, ¾H, H
0.014–0.012	24	24	O, ½H, ¾H, H
0.011–0.0095	24	18	O, ½H, ¾H, H
0.0085	24	18	O, ¾H, H
0.008–0.0075	24	16	O, ¾H, H
0.007	18	16	O, ¾H, H
0.006	18	12	O, ¾H, H

STANDARD ONE SIDE BRIGHT FINISH

Thickness, Inch	Maximum Rolling Limit,[1] Inches	Available Tempers
0.067–0.054	30	O, H
0.053–0.043	30	O, ¾H, H
0.042–0.027	30	O, ¼H,[3] ½H,[3] ¾H, H
0.026–0.024	30	O, ¼H, ½H,[3] ¾H, H
0.023–0.022	30	O, ¼H, ½H,[3] ¾H, H
0.021–0.017	30	O, ¼H, ½H, ¾H, H
0.016–0.015	30	O, ½H, ¾H, H
0.014	30	O, ½H, ¾H, H
0.013–0.012	30	O, ½H, ¾H, H
0.011–0.0095	24	O, ½H, ¾H, H
0.009–0.0085	24	O, ¾H, H
0.008–0.007	18	O, ¾H, H
0.006	14	O, ¾H, H

STANDARD BRIGHT FINISH (TWO SIDES)

Thickness, Inch	Maximum Rolling Limit,[1] Inches	Available Tempers
0.053–0.043	24	O, H
0.042–0.024	24	O, ¼H, ½H, ¾H, H
0.021–0.017	24	O, ¼H, ½H, ¾H, H
0.016–0.012	24	O, ½H, ¾H, H
0.011–0.0095	24	O, ½H, ¾H, H

[1] Maximum diameter of circle same as maximum width of sheet indicated under rolling limits.

[2] Not available in one-side bright mill finish.

[3] Maximum rolling width for this temper is 24 inches.

TABLE 38

Commercial Sizes of 52S Flat Sheet[1]

Thickness, Inch	Standard[2] Width, Inches	Maximum Rolling Limits		Maximum Stretcher Limits 52S
		Width,[3] Inches	Length, Feet	
0.249–0.172	48	84	24	90″ x (4)
0.171–0.136	48	72	24	90″ x (4)
0.135–0.096	48	72	24	88″ x (4)
0.095–0.086	48	72	24	(4)
0.085–0.077	48	72	24	(4)
0.076–0.054	48	60	20	(4)
0.053–0.038	48	60	14	(4)
0.037–0.030	48	48	14	(4)
0.029–0.024	36	42	12	(4)
0.023–0.019	36	42	10	(4)
0.018–0.015	24	36	10	(4)
0.014–0.012	24	30	8	(4)
0.011–0.010	16	24	8	(4)

[1] Available in tempers O to H with the following limitations: maximum thickness for H temper, 0.128 inch; for ¾H temper, 0.162 inch. Minimum thickness for ¼H temper, 0.017 inch. The degree of flatness obtainable in ¼H and ½H sheet is greater than in O, ¾H and H.

[2] Refer to Table 35, page 133, for Alcoa Standard Sizes.

[3] Maximum diameter of circle same as maximum width of sheet.
Maximum width of sheet in the hard temper (H) is 54 inches and in the three-quarter hard temper (¾H) is 60 inches.

[4] Greater than rolling limits.

TABLE 39

Commercial Widths of 52S Coiled Sheet

Thickness, Inch	Maximum Rolling Limits,[1] Inches	Available Tempers
0.102–0.086	24	O, ¼H, H
0.085–0.054	24	O, ¼H, ½H, H
0.053–0.024	24	O, ¼H, ½H, ¾H, H
0.023–0.017	24	O, ¼H, ½H, ¾H, H
0.016–0.012	24	O, ½H, ¾H, H
0.011–0.0095	16	O, ½H, ¾H, H
0.009–0.0075	15	O, ¾H, H
0.007	12	O, ¾H, H

[1] Maximum diameter of circle same as maximum width of sheet indicated under rolling limits.

TABLE 40

Commercial Sizes of Heat-Treatable Alloy Flat Sheet

61S in O, W and T Tempers

Thickness, Inch	Standard[1] Width, Inches	Maximum Rolling Limits		Diameter of Circle, Inches	Stretcher Maximum
		Width, Inches	Length, Feet		
0.249–0.136	48	102	24	96	90″ x (2)
0.135–0.096	48	102	24	96	88″ x (2)
0.095–0.068	48	90	24	90	86″ x (2)
0.067–0.061	48	84	24	84	(2)
0.060–0.048	48	72	18	72	(2)
0.047–0.038	48	60	18	60	(2)
0.037–0.030	48	48	18	48	(2)
0.029–0.019	36	42	16	42	(2)
0.018–0.015	36	36	14	36	(2)
0.014–0.010	24	28	14	28	(2)

[1] Refer to Table 35, page 134, for Alcoa Standard Sizes.
[2] Greater than rolling limits.

TABLE 41

Commercial Sizes of 24S and Alclad 24S Alloy Flat Sheet

O and T Tempers

Thickness, Inch	Standard[1] Width, Inches	Maximum Commercial Dimensions[2]	
		Width, Inches	Length, Feet
0.249–0.061	48	60	24
0.060–0.038	48	60	18
0.037–0.030	48	48	18
0.029–0.025	48	48	16
0.024–0.019	36	42	16
0.018–0.015	36	36	14
0.014–0.010	28	28	14

[1] Refer to Table 35, page 134, for Alcoa Standard Sizes.
[2] All these sizes are within the limits of the stretcher.
Maximum diameter of circle same as maximum width of sheared sheet.

TABLE 42
Maximum Commercial Sizes of Flat Sheet and Plate 24S-RT and Alclad 24S-RT

Thickness, Inch	Rolling Limits, Maximum Width, Inches	
	Lengths up to 12 Feet	Lengths Greater Than 12 Feet to 18 Feet
0.500–0.250	48	..
0.249–0.136	48	..
0.135–0.096	48	..
0.095–0.077	48	..
0.076–0.061	48	42
0.060–0.048	42	36
0.047–0.038	36	36
0.037–0.030	36	36
0.029–0.024	30	..
0.023–0.022	24	..
0.021–0.019	24	..

TABLE 43
Commercial Sizes of Alclad 14S[3], 75S and Alclad 75S Alloy Flat Sheet

O and T Tempers

Thickness, Inch	Standard[1] Width, Inches	Maximum Commercial Dimensions[2]	
		Width, Inches	Length, Feet
0.204–0.061	48	60	24
0.060–0.038	48	60	18
0.037–0.030	48	48	18
0.029–0.025	36	36	16
0.024–0.019	36	36	16
0.018–0.016	36	36	14

[1] Refer to Table 35, page 134, for Alcoa Standard Sizes of Alclad 75S.
[2] All these sizes are within the limits of the stretcher.
Maximum diameter of circle same as maximum width of sheared sheet.
[3] Minimum thickness for Alclad 14S is 0.020 inch.

TABLE 44
Maximum Commercial Widths of Heat-Treatable Alloy Coiled Sheet

24S, Alclad 24S, 75S and Alclad 75S in O and T Tempers and Alclad 14S[1] and 61S in O, W and T Tempers

Thickness, Inch	Maximum Rolling Limit, Inches	
	W or T	O or As-Rolled
0.102–0.068	..	24
0.067–0.030	16	24
0.029–0.019	14	24
0.018–0.015	12	24
0.014–0.012	12	16

[1] Minimum thickness for Alclad 14S is 0.020 inch and for 75S and Alclad 75S is 0.016 inch.

TABLE 45

Maximum Commercial[1] Sizes of Plate[2]

Alloys 2S and 3S

Thickness, Inches	Maximum Width, Inches	Maximum Length for Maximum Width, Feet	Maximum Length (Feet) for Indicated Widths							
			Widths 40″ or less	Width 60″	Width 72″	Width 84″	Width 96″	Width 108″	Width 120″	Width 132″
3	92	7.6	17.7	11.8	9.9	8.4	....	....	....	....
2¾	96	8.0	19.3	12.8	10.6	9.1	8.0	....	....	....
2½	101	8.4	21.2	14.2	11.7	10.0	8.7	....	....	....
2¼	106	8.8	22.8	15.2	12.6	10.8	9.5	....	....	....
2	113	9.4	26.5	17.6	14.6	12.5	10.8	9.7	....	....
1¾	120	10.0	30.3	20.1	16.7	14.3	12.5	11.1	10.0	....
1½	130	10.8	35.4	23.6	19.6	16.8	14.7	13.0	11.7	....
1¼	132	12.9	42.5	28.3	23.6	20.2	17.6	15.6	14.0	12.9
1	132	16.2	53.1	35.4	28.5	24.4	21.3	18.9	17.0	16.2
⅞	132	18.5	60.8	40.5	33.7	28.8	25.2	22.4	20.1	18.5
¾	132	21.6	70.7	47.0	39.2	33.6	29.4	26.1	23.4	21.6
⅝	132	25.8	72.0	56.7	47.3	40.5	35.4	31.4	28.2	25.8
½	132	32.2	60.0	60.0	59.0	50.5	44.0	39.1	35.1	32.2
⅜	120	41.8	40.0	60.0	72.0	67.2	58.8	52.1	41.8	....
¼	102	48.0	36.0	50.0	60.0	60.0	60.0	....	....	....

[1] For thicknesses or lengths intermediate between those listed, available dimensions are in proportion within the limits of the manufacturing equipment, and will be quoted on request.

[2] The dimensions shown are subject to the following limitations:

(a) The sizes shown apply to plate in the as-rolled temper.
(b) The maximum limiting sizes of plate in any alloy in the soft (O) temper are:
  Lengths to 36 feet for widths up to 100 inches.
  Lengths to 30 feet for widths over 100 inches to maximum width of 118 inches.
(c) Maximum diameter of circle same as maximum width of plate except 118 inches is maximum diameter for annealed (O) temper circles.
(d) Plate can be supplied in the following tempers:
  Thickness 3 inches to 2 inches—As-rolled, Soft (O).
  Thickness less than 2 inches to 1 inch—
    As-rolled, Soft (O), Quarter-Hard (¼H).
  Thickness less than 1 inch to ¼ inch—
    As-rolled, Soft (O), Quarter-Hard (¼H), Half-Hard (½H).
(e) Flatness. The degree of flatness which can be obtained depends on the alloy and temper and upon the dimensions of the plate:
  The limiting maximum size for stretcher-leveled plate is ⅞ inch thick by 90 inches wide in all commercial lengths.
  Plate wider than 90 inches and/or thicker than ⅞ inch is supplied roller-leveled.
  Plate thicker than 1 inch is supplied as flat as can be produced on the rolling mills.
(f) Shearing. Unless otherwise specified, plates in all commercial widths in thicknesses up to 1 inch are sheared. Minimum sheared widths are as follows:

Thickness	*Minimum sheared width*
0.250 inch to 0.375 inch	6 inches
0.376 inch to 1.000 inch	8 inches for lengths up to 10 feet. 18 inches for lengths greater than 10 feet.

  Thicker plate or narrower widths must be sawed.
  Plate circles are sheared, unless otherwise specified, as follows:
  Thicknesses ¼ inch–⅝ inch inclusive.
  Diameters 17½ inches to 96 inches inclusive.
  Thicker circles and larger diameters are sawed.
  Method of cutting smaller diameters subject to special inquiry.

TABLE 46

Maximum Commercial[1] Sizes of Plate[2]

Alloy 52S

Thickness, Inches	Maximum Width, Inches	Maximum Length for Maximum Width		Maximum Length (Feet) for Indicated Widths						
		Inches	Feet	Widths 43″ or less	Width 60″	Width 72″	Width 84″	Width 96″	Width 108″	Width 120″
3	82	82	6.8	12.9	9.1	7.6	....	....	....	....
2¾	85	85	7.1	14.0	10.0	8.3	....	....	....	....
2½	87	87	7.2	15.4	11.0	9.1	....	....	....	....
2¼	94	94	7.8	17.1	12.2	10.1	8.5	....	....	....
2	100	100	8.3	19.3	13.8	11.5	9.7	....	....	....
1¾	107	107	8.9	22.1	15.7	13.0	11.1	9.7	....	....
1½	116	116	9.7	25.8	18.3	15.2	12.8	11.4	10.2	....
1¼	120	130	10.8	30.9	22.0	18.3	15.6	13.6	12.0	10.8
1	120	166	13.8	38.6	27.6	23.0	19.7	17.2	15.2	13.8
⅞	120	190	15.8	44.1	31.5	26.2	22.4	19.6	17.4	15.8
¾	120	222	18.5	51.5	36.8	30.6	26.2	22.8	20.2	18.5
⅝	120	266	22.2	60.0	44.2	36.8	30.5	26.6	23.6	22.2
½	120	332	27.7	60.0	55.0	45.7	39.0	34.0	30.2	27.7
⅜	96	555	46.2	40.0	50.0	61.3	52.5	46.2	....	....
¼	90	600	50.0	36.0	40.0	50.0	50.0	....	....	....

[1] For thicknesses or lengths intermediate between those listed, available dimensions are in proportion within the limits of the manufacturing equipment, and will be quoted on request.

[2] The dimensions shown are subject to the following limitations:

(a) The sizes shown apply to plate in the as-rolled temper.

(b) In the quarter-hard (¼H) and half-hard (½H) tempers, the maximum limiting lengths are:

30 feet for widths up to 100 inches.

24 feet for widths greater than 100 inches to maximum width shown in the table.

(c) The maximum limiting sizes of plate in any alloy in the soft (O) temper are:

Lengths to 36 feet for widths up to 100 inches.

Lengths to 30 feet for widths over 100 inches to maximum width of 118 inches.

(d) Maximum diameter of circle same as maximum width of plate except 118 inches is maximum diameter for annealed (O) temper circles.

(e) Plate can be supplied in the following tempers:
Thickness 3 inches to 2 inches—As-rolled, Soft (O).

Thickness less than 2 inches to 1 inch—
As-rolled, Soft (O), Quarter-Hard (¼H).

Thickness less than 1 inch to ¼ inch—
As-rolled, Soft (O), Quarter-Hard (¼H), Half-Hard (½H).

(f) Flatness. The degree of flatness which can be obtained depends on the alloy and temper and upon the dimensions of the plate:

The limiting maximum size for stretcher-leveled plate is ⅞ inch thick by 90 inches wide in all commercial lengths.

Plate wider than 90 inches and/or thicker than ⅞ inch is supplied roller-leveled.

Plate thicker than 1 inch is supplied as flat as can be produced on the rolling mills.

(g) Shearing. Unless otherwise specified, plates in all commercial widths in thicknesses up to ⅝ inch are sheared. Minimum sheared widths are as follows:

Thickness	*Minimum sheared width*
0.250 inch to 0.375 inch	6 inches
0.376 inch to 0.625 inch	8 inches for lengths up to 10 feet. 18 inches for lengths greater than 10 feet.

Thicker plate or narrower widths must be sawed—except that rough sheared plate 0.626 inch to 1 inch thick, 24 inches or over in width and 72 inches to 120 inches long can be supplied if so specified. The length and width tolerances for rough sheared plate are +1 inch, −0 inch.

Plate circles are sheared, unless otherwise specified, as follows:

Thicknesses ¼ inch to ⅝ inch inclusive.

Diameters 17½ inches to 96 inches inclusive.

Thicker circles and larger diameters are sawed.

Method of cutting smaller diameters subject to special inquiry.

TABLE 47

Maximum Commercial[1] Sizes of Heat-Treatable Alloy Plate[2]

Alloys 24S and 61S

Alloys	Thickness, Inches	Maximum Width, Inches	Maximum Length for Maximum Width		Maximum Length (Feet) for Indicated Widths				
			Inches	Feet	Widths 43″ or less	Width 60″	Width 72″	Width 84″	Width 96″
61S	3	60	60	5.0	7.1	5.0	....	....	...
61S	2¾	63	63	5.2	7.7	5.5	....	....	...
61S	2½	66	66	5.5	8.5	6.0	....	....	...
61S	2¼	70	70	5.8	9.5	6.8	....	....	...
24S, 61S	2	74	74	6.2	10.0	7.6	6.3	....	...
24S, 61S	1¾	79	79	6.6	10.0	8.7	7.3	....	...
24S, 61S	1½	86	86	7.1	10.0	10.0	8.4	7.2	...
24S, 61S	1¼	94	94	7.8	10.0	10.0	10.0	8.8	...
24S, 61S	1	105	105	8.7	10.0	10.0	10.0	10.0	9.5
24S	⅞	44	286	23.8	24.4	....	....	....	...
24S	¾	51	286	23.8	28.4	....	....	....	...
24S	⅝	62	286	23.8	34.1	24.4	....	....	...
24S	½	78	286	23.8	36.0	30.5	25.4	....	...
24S	⅜	84	348	29.0	36.0	36.0	33.9	29.0	...
24S	¼	72	360	30.0	30.0	30.0	30.0	....	...
61S	⅞	88	143	11.9	24.4	17.5	14.6	12.5	...
61S	¾	90	163	13.6	28.4	20.5	16.9	14.5	...
61S	⅝	90	196	16.3	34.1	24.4	20.5	17.4	...
61S	½	90	246	20.5	36.0	30.5	25.4	21.8	...
61S	⅜	84	348	29.0	36.0	36.0	33.9	29.0	...
61S	¼	72	360	30.0	30.0	30.0	30.0	....	...

[1] In some cases larger sizes can be produced by means of special manufacturing practices; requirements for larger sizes should be the subject of special inquiry. In many cases the maximum sizes listed are determined by available flattening equipment rather than rolling capacity, in which cases larger sizes may be produced in the soft (O) temper. These are not listed since these alloys are used almost exclusively in the heat-treated tempers. For thicknesses or lengths intermediate between those listed, available dimensions are in proportion within the limits of manufacturing equipment, and will be quoted on request.

[2] The dimensions shown are subject to the following limitations:

(a) The maximum limit in length of plates in these alloys in the soft (O) temper is 30 feet.

(b) Maximum diameter of circles same as maximum width of plate.

(c) Flatness. The degree of flatness which can be obtained depends upon the alloy and temper, and upon the dimensions of the plate. The maximum degree of flatness in these alloys in the heat-treated tempers, in thicknesses over ½ inch, can be supplied in lengths up to 120 inches.

(d) Shearing. Unless otherwise specified, plates in all commercial widths in thicknesses up to the limits shown below are sheared. The minimum widths of sheared plate are as follows:

Thickness	*Minimum sheared width*
24S, 61S 0.250 inch to 0.375 inch	6 inches
61S 0.376 inch to 0.625 inch 24S 0.376 inch to 0.500 inch	8 inches for lengths up to 10 feet. 18 inches for lengths greater than 10 feet.

Thicker plate or narrower widths must be sawed—except that rough sheared 61S plate 0.626 inch to 1 inch thick, and 24S plate 0.501 inch to 1 inch thick, can be supplied if so specified in widths of 24 inches and over and in lengths of 72 inches to 120 inches. The length and width tolerances for rough sheared plate are +1 inch, −0 inch.

Plate circles 17½ inches diameter and larger in ¼ inch thickness are sheared, unless otherwise specified. The following sizes are sawed.

Diameters 7½ inches to 17½ inches, thickness ¼ inch.

Diameters 7½ inches and larger, over ¼ inch thickness.

Diameters smaller than 7½ inches quoted specially.

TABLE 48

Maximum Commercial[1] Sizes of Heat-Treatable Alloy Plate[2]

Alloys Alclad 14S, 75S and Alclad 75S

Alloys	Thickness, Inches	Maximum Width, Inches	Maximum Length for Maximum Width		Maximum Length (Feet) for Indicated Widths				
			Inches	Feet	Widths 43″ or less	Width 60″	Width 72″	Width 84″	Width 96″
Alclad 14S, 75S, Alclad 75S	2	74	74	6.2	10.0	7.6	6.3	....	...
	1¾	79	79	6.6	10.0	8.7	7.3	....	...
	1½	86	86	7.1	10.0	10.0	8.4	7.2	...
	1¼	94	94	7.8	10.0	10.0	10.0	8.8	...
	1	105	105	8.7	10.0	10.0	10.0	10.0	9.5
Alclad 14S	⅞	40	288	24.0	25.0	....	....	....	...
	¾	47	288	24.0	29.0	....	....	....	...
	⅝	57	288	24.0	34.0	25.0	....	....	...
	½	72	288	24.0	36.0	31.0	26.0	....	...
	⅜	84	348	29.0	36.0	36.0	33.9	29.0	...
	¼	72	360	30.0	30.0	30.0	30.0	....	...
75S, Alclad 75S	⅞	38	288	24.0	25.0	....	....	....	...
	¾	41	288	24.0	29.0	....	....	....	...
	⅝	49	288	24.0	34.0	25.0	....	....	...
	½	62	288	24.0	36.0	31.0	26.0	....	...
	⅜	84	348	29.0	36.0	36.0	33.9	29.0	...
	¼	72	360	30.0	30.0	30.0	30.0	....	...

[1] In some cases larger sizes can be produced by means of special manufacturing practices; requirements for larger sizes should be the subject of special inquiry. In many cases the maximum sizes listed are determined by available flattening equipment rather than rolling capacity, in which cases larger sizes may be produced in the soft (O) temper. These are not listed since these alloys are used almost exclusively in the heat-treated tempers. For thicknesses or lengths intermediate between those listed, available dimensions are in proportion within the limits of manufacturing equipment, and will be quoted on request.

[2] The dimensions shown are subject to the following limitations:

(a) The maximum limit in length of plates in these alloys in the soft (O) temper is 30 feet.

(b) Maximum diameter of circles same as maximum width of plate.

(c) Flatness. The degree of flatness which can be obtained depends upon the alloy and temper, and upon the dimensions of the plate. The maximum degree of flatness in these alloys in the heat-treated tempers, in thicknesses over ½ inch, can be supplied in lengths up to 120 inches.

(d) Shearing. Unless otherwise specified, plates in all commercial widths of 6 inches or greater and in thickness up to 0.375 inch, inclusive, are sheared. Thicker plates or narrower widths must be sawed.

Plate circles 17½ inches diameter and larger in ¼ inch thickness are sheared, unless otherwise specified. The following sizes are sawed.

Diameters 7½ inches to 17½ inches, thickness ¼ inch.

Diameters 7½ inches and larger, over ¼ inch thickness.

Diameters smaller than 7½ inches quoted specially.

TABLE 49
Tubing—Alcoa Standard Sizes
3S-½H, 24S-T, 52S-O, 61S-T
(DEFINITE 12-FOOT LENGTHS)

Wall Thickness, Inch	Available Alloys	Outside Diameter, Inches														
		3	2½	2	1¾	1½	1¼	1	⅞	¾	⅝	½	⅜	5/16	¼	3/16
0.028	3S½H	...	...	...	...	...	...	...	...	...	*	*	*	...	...	...
0.035	3S½H	...	...	*	...	*	*	*	*	*	*	*	*	...	*	*
	24S-T	...	...	...	...	...	*	*	...	*	*	*	*	...	*	...
	52S-O	...	...	...	...	...	...	...	...	...	...	...	*	*	*	*
	61S-T	...	...	...	...	...	*	*	...	*	*	*	...	...	...	...
0.049	3S½H	...	*	*	*	*	*	*	...	*	*	*	*	...	*	...
	24S-T	...	...	...	...	*	*	*	...	*	*	*	...	...	...	...
	52S-O	...	...	...	...	...	...	*	...	*	*	*	*	...	...	...
	61S-T	...	...	*	...	*	*	*	...	*	...	...	...	...	...	...
0.065	3S½H	*	*	*	*	*	*	*	*	...	*	*	...	...	...	...
	24S-T	*	*	*	...	*	*	*	...	...	*	*	...	...	...	...
	52S-O	...	...	...	...	...	...	*	...	...	...	...	...	...	...	...
	61S-T	...	...	*	...	*	*	*	...	...	...	...	...	...	...	...
0.083	24S-T	*	...	*	...	*	*	*	...	...	...	...	...	...	...	...
	61S-T	...	...	...	...	...	...	*	...	...	...	...	...	...	...	...
0.120	24S-T	*	*	*	...	*	*	...	...	...	...	...	...	...	...	...

TABLE 50
Commercial Sizes of Alcoa Tread Plate (61S)
Standard Pattern C-100

Thickness, Inch	Standard Sizes, Inches	Maximum Rolling Limits[1]		Approximate Weight, Lb./Sq. Ft.
		Width, Inches	Length, Feet	
⅛	48 x 144	48	24	2.0
3/16	48 x 144	60	24	2.8
	60 x 144	60	24	2.8
¼	48 x 144	60	24	3.7
	60 x 144	60	24	3.7
5/16	....	60	24	4.6
⅜	....	60	24	5.5
	....	60	24	5.5
½	....	60	24	7.3
	....	60	24	7.3

[1] Non-standard sizes and tempers are subject to special inquiry as to next rolling date.

TABLE 51

Condensed List of Commercial Sizes, Structural Shapes

EQUAL ANGLES	UNEQUAL ANGLES		STRUCTURAL CHANNELS	TEES
Size, Inches	Size, Inches	Size, Inches	Depth, Inches	Size, Inches Flange Stem
½ x ½	¾ x ⅜	2½ x 1½	3	1 x 1
⅝ x ⅝	1 x ⅝	2½ x 2	4	1½ x 1¼
¾ x ¾	1 x ¾	3 x 1½	5	1½ x 1½
1 x 1	1¼ x ¾	3 x 2	6	2 x 2
1⅛ x 1⅛	1¼ x 1	3 x 2½	7	2¼ x 2¼
1¼ x 1¼	1½ x ¾	3½ x 2½	8	2½ x 1¼
1½ x 1½	1½ x ⅞	3½ x 3	9	2½ x 2½
1¾ x 1¾	1½ x 1	4 x 3	10	2½ x 3
2 x 2	1½ x 1¼	4 x 3½	12	3 x 2½
2½ x 2½	1⅝ x 1¼	5 x 2½	**CAR CHANNELS**	3 x 3
3 x 3	1¾ x 1⅛	5 x 3	2 5	4 x 2
3½ x 3½	1¾ x 1¼	5 x 3½	2½ 6	4 x 3
4 x 4	2 x 1¼	6 x 3½	3 8	4 x 4
5 x 5	2 x 1⅜	6 x 4	4 10	4 x 5
6 x 6	2 x 1½		**I-BEAMS**	4½ x 3
	2 x 1¾		3	5 x 3
	2¼ x 1½		4	**ZEES** Depth, Inches
	2½ x 1¼		5	1¾
			6	2
			7	2⅜
			8	3
			WING CHANNELS	4
			3⅓ x ¾	4 1/16
			4 x ¾	4⅛
			4 x 1⅛	5
			4 x 2	5 1/16
			4¾ x 2	
			5 x 1½	
			5 x 1⅞	
			7½ x 3⅜	
			8¾ x 3⅛	
			H-BEAMS	
			4	
			5	
			6	
			8	

Many of the above sections are obtainable in several different flange, web or stem thicknesses. Consult nearest sales office.

Elements of sections are given in "Structural Aluminum Handbook" published by Aluminum Company of America.

Above list includes both extruded and rolled shapes.

Maximum length in a heat-treated alloy—Smaller sizes 45 feet
—Larger sizes 85 feet

TABLE 52

Range of Commercial Sizes of Round Tubing

Thickness		Minimum O.D., Inches		Maximum O.D., Inches							
Stubs Gauge	Inch	2S, 61S	24S, 52S	2S-O, 61S-O	2S-1/4H	2S-1/2H	2S-3/4H	2S-H	61S-T	24S-T	52S-O
..	0.500	2 3/4	...	7 1/4	9	7 3/4	5	3 3/4	9 1/2	7 3/4	...
..	0.484	2 3/4	...	7 15/32	9 7/32	7 23/32	5 1/4	4	9 15/32	7 15/16	...
..	0.480	2 1/2	...	7	7	7	5 1/4	4	7	8	...
..	0.468	2 1/2	...	7 3/4	9 1/2	8 1/4	5 1/2	4	10	8 1/4	...
..	0.453	2 1/2	...	7 31/32	9 15/32	8 7/32	5 1/2	4 1/4	9 15/32	8 1/2	...
..	0.450	1 1/2	2 1/4	7	7	7	5 1/2	4 1/4	7	8 1/2	3 1/2
..	0.437	1 1/2	2 1/4	8 1/4	10	8 1/2	5 1/2	4 1/4	10 3/4	8 13/16	3 1/2
..	0.421	1 1/2	2 1/4	8 15/32	10 15/32	8 31/32	5 1/2	4 1/4	11 5/32	9	3 1/2
..	0.406	1 1/2	2 1/4	8 3/4	10 3/4	9	6	4 1/2	11 1/8	9	3 1/2
..	0.400	1 1/2	2 1/4	7	7	7	6	4 1/2	7	8 7/8	3 1/2
..	0.390	1 1/2	2 1/4	8 31/32	11 1/32	9 15/32	6	4 1/2	11 1/32	8 7/8	3 1/2
..	0.375	1 3/8	2 1/4	10	11	10 1/4	6 1/4	4 3/4	11	8 7/8	3 1/2
..	0.359	1 3/8	2 1/4	9 31/32	10 29/32	10 15/32	6 1/4	5 1/4	10 29/32	8 3/4	3 1/2
..	0.350	1 3/8	1 7/8	7	7	7	6 1/2	5 1/4	7	8 3/4	3 1/2
..	0.344	1 3/8	1 7/8	10	10 7/8	10 7/8	6 1/2	5 1/4	10 7/8	8 3/4	3 1/2
..	0.328	1 3/8	1 7/8	10 15/32	10 25/32	10 25/32	7 7/32	5 1/2	10 25/32	8 11/16	3 1/2
..	0.320	1	1 5/8	7	7	7	7	5 1/2	7	8 11/16	3 1/2
..	0.312	1	1 5/8	10 3/4	10 3/4	10 3/4	7 1/2	5 1/2	10 3/4	8 11/16	3 1/2
1	0.300	7/8	1 3/8	7	7	7	7	6	7	8 1/2	3 1/2
..	0.297	7/8	1 3/8	10 21/32	10 21/32	10 21/32	7 23/32	6	10 21/32	8 1/2	3 1/2
2	0.284	7/8	1 1/4	7	7	7	7	6 1/4	7	8 1/2	3 1/2
..	0.281	7/8	1 1/4	10 5/8	10 7/8	10 7/8	8 1/4	6 1/4	10 7/8	8 1/2	3 1/2
..	0.266	7/8	1 1/4	10 17/32	10 25/32	10 25/32	8 23/32	6 1/2	10 25/32	8 3/8	3 1/2
3	0.259	3/4	1 1/8	7	7	7	7	6 3/4	7	8 3/8	3 1/2
..	0.250	3/4	1 1/8	10 3/4	10 3/4	10 3/4	9 1/4	7	10 3/4	8 3/8	3 1/2
4	0.238	5/8	1	7	7	7	7	7	7	8 3/16	3 1/2
..	0.234	5/8	1	10 21/32	10 21/32	10 21/32	9 15/32	7 15/32	10 21/32	8 3/16	3 1/2
5	0.220	5/8	7/8	7	7	7	7	7	7	8 3/16	3 1/2
..	0.218	5/8	7/8	10 5/8	10 5/8	10 5/8	10 3/8	8	10 5/8	8 1/16	3 1/2
6	0.203	9/16	3/4	10 17/32	10 17/32	10 17/32	10 9/32	8 15/32	10 17/32	8 1/16	3 1/2
..	0.187	9/16	3/4	10 1/2	10 1/2	10 1/2	10 1/4	9 1/4	10 1/2	8 1/16	3 1/2
7	0.180	1/2	5/8	7	7	7	7	7	7	8 1/16	3 1/2
..	0.171	1/2	5/8	10 13/32	10 13/32	10 13/32	10 3/8	9 31/32	10 13/32	8	3 1/2
8	0.165	7/16	1/2	7	7	7	7	7	7	8	3 1/2
..	0.156	7/16	1/2	10 3/8	10 3/8	10 3/8	10 3/8	10	10 3/8	7 15/16	3 1/2
9	0.148	3/8	7/16	7	7	7	7	7	7	7 13/16	3 1/2

TABLE 52—*Concluded*

Range of Commercial Sizes of Round Tubing

Thickness		Minimum O.D., Inch		Maximum O.D., Inches							
Stubs Gauge	Inch	2S, 61S	24S, 52S	2S-O, 61S-O	2S-¼H	2S-½H	2S-¾H	2S-H	61S-T	24S-T	52S-O
..	0.140	3/8	7/16	10 9/32	10 9/32	10 9/32	10 9/32	9 31/32	9 15/32	7 13/16	3 1/2
10	0.134	5/16	3/8	7	7	7	7	7	7	7 13/16	3 1/2
..	0.125	5/16	3/8	10 1/4	10 1/4	10 1/4	10 1/4	10 1/4	8 3/4	7 13/16	3 1/2
11	0.120	1/4	5/16	7	7	7	7	7	7	7 3/4	3 1/2
12	0.109	1/4	1/4	9 15/32	9 15/32	9 15/32	9 15/32	9 15/32	8 23/32	7 3/4	3 1/2
13	0.095	1/4	1/4	7	7	7	7	7	7	7 3/4	3 1/2
..	0.093	1/4	1/4	9 1/4	9 1/4	9 1/4	9 1/4	9 1/4	8 1/4	7 3/4	3 1/2
14	0.083	3/16	3/16	7	7	7	7	7	7	7 11/16	3 1/2
..	0.078	3/16	3/16	8 31/32	8 31/32	8 31/32	9	9	7 23/32	7 5/8	3 1/2
15	0.072	3/16	3/16	7	7	7	7	7	6 3/4	7 5/8	3 1/2
16	0.065	3/16	3/16	7	7	7	7	7	6 3/4	7 9/16	3 1/2
..	0.062	3/16	3/16	9	9	9	9	9	6 3/4	7 9/16	3 1/2
17	0.058	3/16	3/16	7	7	7	7	7	6 1/4	6 1/4	3 1/2
18	0.049	1/8	1/8	7	7	7	7	7	5	5	3 1/2
..	0.046	1/8	1/8	8 31/32	8 31/32	8 31/32	8 31/32	8 31/32	3 3/4	3 3/4	3 1/2
19	0.042	1/8	1/8	6 3/4	6 3/4	6 3/4	6 3/4	6 3/4	3 3/4	3 3/4	3 1/2
20	0.035	1/8	1/8	5	5	5	5	5	3 1/4	3 1/4	3 1/4
21	0.032	1/8	1/8	4	4	4	4	4	2 3/4	2 3/4	2 3/4
22	0.028	1/8	1/8	4	4	4	4	4	2 3/4	2 3/4	2 3/4
23	0.025	1/8	1/8	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	2 1/2	2 1/2	2 1/2
24	0.022	1/8	1/8	3	3	3	3	3	2	2	2
25	0.020	1/8	1/8	2 3/4	2 3/4	2 3/4	2 3/4	2 3/4	1 3/8	1 3/8	1 3/8
26	0.018	1/8	1/8	2 1/2	2 1/2	2 1/2	2 1/2	2 1/2	9/16	9/16	9/16
27	0.016	1/8	1/8	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	7/16	7/16	7/16
28	0.014	1/8	1/8	1	1	1	1	1	3/8	3/8	3/8
29	0.013	1/8	1/8	1	1	1	1	1	5/16	5/16	5/16
30	0.012	1/8	1/8	5/8	5/8	5/8	5/8	5/8	1/4	1/4	1/4
31	0.010	1/8	1/8	9/16	9/16	9/16	9/16	9/16	3/16	3/16	3/16

TABLE 53

Range of Commercial Sizes of Wire, Rod and Bar[1]

ALL ALLOYS

COMMODITY	SMALLEST	LARGEST
	Diameter, Inches	Diameter, Inches
Round Wire—Drawn	0.0126	0.374
Round Rod—Cold-Finished	3/8	3
Round Rod—Rolled	1 9/16	8
	Distance Across Flats, Inches	Distance Across Flats, Inches
Square Wire—Drawn	1/32 x 1/32	11/32 x 11/32
Square Bar—Cold-Finished	3/8 x 3/8	1 1/2 x 1 1/2
Square Bar—Rolled	1 5/8 x 1 5/8	4 x 4
Hexagonal Wire—Drawn	1/32	11/32
Hexagonal Bar—Cold-Finished	3/8	2
Hexagonal Bar—Rolled	1 9/16	3
Octagonal Wire—Drawn	1/4	1/4
Octagonal Bar—Cold-Finished	3/8	1 3/16
	Dimensions, Inch	Dimensions, Inches
Square Edge Rectangular Wire—Drawn	1/16 x 1/8	1/4 x 5/16
Square Edge Rectangular Bar, 2S or 3S Alloy—Cold-Finished	1/16 x 3/8	1 1/2 x 4
Square Edge Rectangular Bar, Heat-treatable Alloy—Cold-Finished	1/16 x 3/8	1 1/2 x 4
Square Edge Rectangular Bar—Rolled	3/32 x 1 1/8	3 x 7
Round Edge Rectangular Bar—Rolled	1/8 x 5/8	1/2 x 6
	Dimensions, Inch	Dimensions, Inches
Half Round Wire—Drawn	1/32 x 1/16	3/32 x 3/16
Half Oval Wire—Rolled	3/64 x 1/8	3/64 x 3/16
Oval Bar—Cold-Finished	7/32 x 7/16	7/32 x 7/16
Half Oval Bar—Rolled	1/4 x 1	1/4 x 1 3/4

[1] This table indicates the range of commercial sizes. All alloys are not produced in all of the sizes listed; consult the sales representative of Aluminum Company of America for details. See Table 55 for sizes of flattened wire and flattened and slit wire.

TABLE 54

Commercial Sizes of Rough-Rolled, Round-Cornered Squares and Rectangles

ALL ALLOYS

Thickness, Inches		Width, Inches
2 to 3.99	by	5⅝ to 16
4 to 5.99	by	4 to 16
6 to 7.99	by	6 to 16
8 to 12.00	by	8 to 16

TABLE 55

Commercial Sizes of Flattened Wire and Flattened and Slit Wire

ALL ALLOYS

FLATTENED WIRE (Round Edges)		FLATTENED AND SLIT WIRE (Slit Edges)	
Thickness, Inch	Width, Inches	Thickness, Inch	Width, Inches
Straight Lengths:		*Straight Lengths:*	
0.039 to 0.187	All Widths	0.039 to 0.080	0.125 to 3.50
Spooled:		*Spooled:*	
0.010 to 0.017	Up to 0.125	0.010 to 0.080	Up to 0.250
0.018 to 0.029	Up to 0.250		
0.030 to 0.042	Up to 0.750		
0.043 to 0.125	Up to 0.250		
Coiled:		*Coiled:*	
0.030 to 0.042	0.251 to 0.750	0.043 to 0.080	Up to 0.250
0.043 to 0.125	Up to 0.625	0.010 to 0.059	0.251 to 4.75
0.043 to 0.125	0.251 to 0.625	0.060 to 0.080	0.251 to 4.75
0.043 to 0.125	0.625 to 2.000		
0.126 to 0.187	Up to 0.625		

index

INDEXES covering photos (below) and tables (page 86) as well as a topical index (page 156) are presented for your convenience.

INDEX TO PHOTOS

Mining aluminum ore (bauxite) 8

A step in the wet chemical process for obtaining alumina, or aluminum oxide, from bauxite. The alumina is later reduced to aluminum 10

Powerful testing machine, Aluminum Research Laboratories 14

Forged aluminum alloy propeller blades 18

Aluminum is extensively used for chemical equipment 20

"Capping" aluminum beer barrel half in a 450-ton press 28

Rolling aluminum foil 32

Products produced by impact extrusion and press forging 36

Forging an airplane propeller blade 40

Propeller blades suspended in rack for heat treatment 46

Lowering a basket of aluminum forgings into a quenching tank, after heat treatment 54

Taking molten aluminum from a holding furnace 56

Aluminum permanent-mold and semi-permanent-mold castings 62

Aluminum die castings 66

Machine-spinning a large aluminum container 70

Electric seam-welding an aircraft part 74

Torch welding aluminum 76

Furnace brazing gasoline tanks for outboard motors 80

TOPICAL INDEX

Explanation of References

When text concerning a subject refers to a related table, reference is made in this manner:

Thermal expansion....16 table 11, 98

which means that thermal expansion is mentioned on page 16, and that reference is made to Table 11 which can be found on page 98.

When reference is made to a table or photograph not mentioned in the related text, no page number precedes the table or photograph, as:

Wire
Commercial tolerances....table 29, 123

which means that Table 29 which covers commercial tolerances for wire can be found on page 123.

A

Abrasive wheels......................81
Absorbent materials..............24, 26
Acetic acid..........................19
Aging..................37, 38, 53, 73, 77
see also Artificial aging; Precipitation heat treatment
High temperature....................31
Room temperature...............31, 37
Air blast..........................52, 53
Air furnaces....................51–2, 55
Alclad coatings....................41–2
Alclad plate......................41, 42
Commercial thickness tolerances..............tables 26, 120
Alclad products..............23, 37, 41–2
Composition........................41
Corrosion resistance..............41–2
Physical properties..................41
Alclad sheet..........23, 38, 41–2, 49, 53
Applications....................23, 42
Artificial aging...............23, 24, 26
Commercial thickness tolerances..............table 26, 120
Corrosion resistance........23, 24, 41–2
Heat treating............23, 51, 52, 53
Mechanical properties............41–2
Mechanical test specimens..........41
Protection.........................23–4
Quenching.......................23, 24
Reheat treating..................23, 24
Salt spray test....................41–2
Strength............................23
Tensile properties...................42
Test specimens....................41–2
Thickness.......................41, 42
Weight..............................42
Alclad sheet assemblies..............53
see also Riveted Alclad sheet assemblies
Alclad tubing........................42
Applications........................42
Alkalis..............................21
Alloy constituents...11–13, 57; table 5, 93
Chromium..................12, 22, 57
Copper...12, 15, 52, 53, 57, 59, 60, 61, 65
Diffusion...........................53
Effect on corrosion resistance........22
Iron..........................12, 57
Magnesium.......12, 22, 57, 60, 61, 63
Manganese..................12, 22, 57
Melting points.......................51
Nickel..........................12, 57
Percentage......12; tables 5 and 6, 93; tables 7 and 8, 94
Redistribution by heat treating......47
Silicon..12, 15, 16, 22, 57, 59, 60, 61, 65, 78, 81
Solid solution............33, 45, 47, 48
Zinc........................12, 57, 60
Alloy selection........7, 13, 26, 34, 37, 68
see also Cast alloys—Selection; Wrought alloys—Selection
Alorco protective compound...........51
Alrok coatings.......................83
Alumina.....................photo, 10
Aluminum-copper alloys...........59, 61
Aluminum-copper-zinc alloys........60–1
Aluminum ore.................photo, 8
Aluminum oxide...............photo, 10
Aluminum paint......................83
Aluminum Research Laboratories..........................photo, 14
Aluminum-silicon alloys........59, 60, 61
American Society for Testing Materials.67
Annealed alloys
Corrosion resistance.................25
Drawing..........................72–3
Ductility............................78
Elongation......................12, 47
Forming..........................37–8
Hardness........................47, 48
Heat treating........................38
Quenching...........................38
Strength.............25, 31, 47, 48, 78
Tensile strength.................11, 12

Annealing....30, 49–50, 75
Annealing temperatures....48, 49–50
Anodic coatings....24, 51, 83
Applications....9, 11, 13
  Aircraft....37, 42, 45; photo, 74
  Aircraft engines....63
  Aircraft propeller blades....photo, 18; photo, 40; photo, 46
  Architecture....9, 34, 59
    Hardware....43
    Industrial....21
    Ornamental effects....44
  Automotive pistons....63
  Beer barrels....photo, 28
  Beverage processing....21
  Bottle and jar closures....34
  Brewing industry....21, 43
  Chemical industries....9, 19; photo, 20; 21, 26, 34, 60
  Chemicals shipping....19, 21
  Chemicals storage....19, 26
  Collapsible tubes....44
  Containers....photo, 70
  Cooking utensils....34, 60, 65
  Crank cases....63
  Cylinder heads....63
  Dairy industry....43, 60
  Diesel engine castings....63
  Dirigibles....42
  Electrical....15
    Conductors....15
  Fermentation reaction equipment....21
  Flatiron soleplates....65
  Food processing....21
  Foods storage....26
  Gasoline tanks....42; photo, 80
  Gums and resins processing....21
  Hypodermic needles....39
  Internal combustion engines....63, 65
  Iron oxide reduction....22
  Light alloys constituent....11
  Liquid-cooled aircraft engine castings.63
  Marine....44
  Marine castings....60
  Marine masts....39
  Metallurgy....9, 11
  Non-structural....34
  Ornamental castings....59–60
  Packaging....44
  Pistons....43, 65
  Pump cylinder housings....63
  Railway cars....21, 44
  Rayon industry....21, 43
  Reducing agent....9, 11
  Refractory metals reduction....11
  Screw machine products....45
  Sewage disposal plants....60
  Shells....44
  Steel deoxidization....11
  Tank cars....21
  Textile industry....19
  Vanadium production....21
  Varnish and lacquer processing....21
  Water tanks and lines....42
  Yeast fermentation....21
Arc welding....77, 78, 79
  Comparison with brazing....79
Arc welding applications....78
Artificial aging..23, 25, 26, 31, 33, 37, 48–9
Artificial aging temperature....48
Artificial aging time....48–9
"As-fabricated" commodities....30
Assemblies....71
  see also Riveted assemblies
  Corrosion resistance....24
  Deflection under load....17
  Distortion....53
  Heat treating....53
Assemblies (Continued)
  Steel....16
  Strength
    Effect of marine atmosphere....24
  Ultimate strength....17
Autographic pyrometers....52
Automatic pyrometric control....52

B

Bar....30; table 1, 89
  Cold finishing....30
  Commercial sizes....table 53, 152
  Commercial tolerances...table 29, 123–4
  Hot working....30
  Mechanical properties specifications.... table 19, 111; table 20, 112; table 22, 114–5; table 23, 116; table 25, 118
  Sizes....39 table 53, 152
  Tempers....table 4, 92
Bauxite....photo, 8; photo, 10
Bend radii....72, 73; 75 table 2, 90
Bending equipment....73
Bituminous paint....83
Blistered surfaces....51
Brazed joints
  Corrosion resistance....80
Brazing....79–80
  Comparison with welding....79
Brazing costs....79
Butt joints....78
Butt welding....79

C

Cast alloys....57–69
  see also Die casting alloys; Permanent mold casting alloys; Sand casting alloys
  Number 12.... 59
  13
    Corrosion resistance....26
  43, 59, 60
    Applications....59–60
    Casting properties....59
    Corrosion resistance....26, 59, 60
    Ductility....59
    Impact resistance....59
    Mechanical properties....60
    Sand castings....59, 60
    Tensile and yield strength....59
  47, 60
    Corrosion resistance....26
    Properties....60
    Sand castings....60
  108, 60
    Sand castings....60
  A108
    Applications....65
    Casting properties....65
    Permanent mold castings....65
  112, 59, 60
    Applications....59
    Machinability....59
    Mechanical properties....59, 60
    Sand castings....59, 60
  B113
    Applications....65
    Permanent mold castings....65
    Properties....65
  C113
    Applications....65
    Permanent mold castings....65
    Properties....65
  122, 63, 65
    Applications....63, 65
    Heat treated sand castings....63
    Permanent mold castings....65
    Properties....63

Cast alloys (Continued)
A132
Applications.....................65
Coefficient of thermal expansion...65
Permanent mold castings..........65
138
Permanent mold castings..........65
Properties.......................65
142, 63, 65
Applications..................63, 65
Heat treated sand castings........63
Permanent mold castings..........65
Properties.......................63
195, 58, 61, 63, 67
Heat treated sand castings...61, 63–4
Heat treating..................64–5
Impact resistance................63
Tensile strength..............61, 63
B195, 67
Permanent mold castings..........67
195–T4, 58, 61, 63, 67
Aging at room temperature........63
Heat treated sand castings.....61, 63
Properties.......................61
B195–T4
Permanent mold castings..........67
Properties.......................67
195–T6, 58, 61
Heat treated sand castings........61
Mechanical properties............61
195–T62, 58, 61
Heat treated sand castings........61
Properties.......................61
212, 59, 60
Applications.....................59
Casting properties...............59
Mechanical properties.........59, 60
Sand castings.................59, 60
Tensile and yield strength.........59
214, 26, 57, 60, 65
Applications.....................60
Corrosion resistance...........26, 60
Mechanical properties............60
Permanent mold castings..........65
Sand castings....................60
A214, 57, 65
Permanent mold castings..........65
Tarnish resistance...............65
B214
Corrosion resistance.............26
218
Corrosion resistance.............26
220
Corrosion resistance.............26
220–T4
Aging at room temperatures.......63
Heat treated sand castings........63
Properties.......................63
A334, 60
Applications.....................60
Properties.......................60
Sand castings....................60
355, 63, 67
Applications..................63, 67
Heat treated sand castings........63
Permanent mold castings..........67
Properties....................63, 67
Tensile strength.................67
A355, 63
Applications.....................63
Heat treated sand castings........63
Properties.......................63
356, 61, 63, 64, 67
Applications.....................67
Casting properties...............61
Corrosion resistance....26, 61, 63, 67
Heat treated sand castings...61, 63–4
Heat treating....................65

Cast alloys (Continued)
356, 61, 63, 64, 67 (Continued)
Impact resistance................63
Mechanical properties............61
Permanent mold castings..........67
Tensile strength...........61, 63, 67
360
Corrosion resistance.............26
645
Mechanical properties............61
Sand castings....................61
Alloying elements...............12, 57
Casting properties........57, 59, 61, 65
Coefficient of thermal expansion.....65; table 11, 98
Composition........57–8; table 6, 93; table 7, 94; table 8, 94
Constituents.......................57
Corrosion resistance......59, 60, 61, 63
Designations....................57–8
Ductility.......................59, 61
Effect of cold working............11
Electrical conductivity...15 table 10, 96
Elongation..............47, 60, 61, 63
Hardness.......................47, 63
Heat treating.12, 57–8, 61, 63–4, 67, 68
High temperature properties.19, 63, 65; table 16, 108–9
Hot working.......................47
Impact resistance...............59, 63
Machinability..............59, 63, 80
Mechanical properties.........17 tables 13–15, 100–6; 57, 59, 61, 63, 67–8
Modification process...............59
Physical properties....64 table 10, 96–7
Properties.............15 table 10, 96
Selection.......................64, 68
Solution heat treatment............47
Specific gravity.........15 table 10, 96
Strength................47, 60, 63, 65
Tarnish resistance.................65
Tensile strength................11, 12; 19 table 16, 108–9; 59, 61, 63
Comparisons....................11
Effect of cold working............11
Thermal conductivity..15 table 10, 96–7
Typical tensile properties.table 16, 108–9
Wear resistance.................63, 65
Weight................15 table 10, 96
Yield strength..............59, 61, 63
Cast iron
Coefficient of thermal expansion.....16
Cast iron tools.....................73
Cast steel tools....................73
Casting equipment..................58
Casting properties.......13, 57, 59, 61, 65
Effect of alloying.................13
Castings.....................39, 57–69
see also Die castings; Permanent mold castings; Sand castings; Semi-permanent mold castings
Applications......................68
Comparisons......................58
Corrosion........................25
Cost comparisons.................58
Design.........................67–9
Electrical conductivity.............15
Fabrication.......................58
Fabrication equipment.......57, 58, 64
Finishing........................58
Gating...........................68
Heat treated castings.........57–8, 61, 63–4, 67, 68
Pouring temperature..............68
Precipitation heat treating..........61
Properties.......................68–9
Risering.........................68
Section thickness...............59, 68

Castings (Continued)
Solution heat treating..............61
Types........................58–67
Welding........................78
Cemented tungsten carbide tipped tools.81
Centerless ground rod
Commercial tolerances.....table 29, 124
Centerless ground wire
Commercial tolerances.....table 29, 124
Chemical properties....9, 11, 19, 22–7, 34, 35, 37, 38, 39, 43, 59–60, 61, 63, 78
Chemicals..............19; photo, 20; 21
Chill-cast alloys....................60
Cleaners..........................21
Coatings..........................26
Alclad........................41–2
Anodic..................24, 51, 83
Paint..................23, 24, 26
Coefficient of thermal expansion......... ....16 table 11, 98; 65
Coiled plate
Commercial thickness..table 26, 119–20
Coiled sheet
Commercial thickness.....table 17, 110; table 26, 119–20
Commercial widths.......table 37, 136; table 39, 137; table 44, 139
Maximum commercial widths.......... ....table 44, 139
Sheared
Width tolerances........table 27, 121
Cold driven rivets...................82
Cold-finished bar
Commercial tolerances.....table 29, 123
Cold-finished rectangles
Commercial tolerances.....table 29, 123
Cold-finished rod
Commercial tolerances.....table 29, 123
Cold-finished wire
Commercial tolerances.....table 29, 123
Cold finishing.......................30
Cold water quenching.............53, 55
Cold worked alloys
Annealing.....................49–50
Cold worked temper designations......33
Cold working..29–30, 31, 33, 48, 49, 50, 72
Effect on strength...........11, 12, 29
Colorless compounds..............9, 21
Commercial aluminum................22
Commercial sizes....tables 36–55, 135–53
Commercial thickness.......table 17, 110
Commercial thickness tolerances......... ....table 26, 119–20
Commercial tolerances.tables 26–34, 119–32
Commercial widths..........table 39, 137
Composition.....64–5; tables 5 and 6, 93; tables 7 and 8, 94
Changes through heat treating.......47
Effect on electrical conductivity......15
Effect on modulus of elasticity.......16
Impurities..........................22
Cooling rates...............49, 50, 53, 55
Cores..............................64
Corrosion compounds...........8, 21, 41
Corrosion prevention.................27
Artificial aging....................48
Coatings...................24, 26, 41
Electrolytic action.................41
Insulation..........................26
Paint................23, 24, 26, 82–3
Corrosion resistance....9, 19, 22–7, 34, 35, 37, 38, 39, 43, 59–60, 61, 63, 78
Acetic acid........................19
Alkalis...........................21
Chemicals............19; photo, 20; 21
Effect of bulk......................25
Effect of heat treating......24–6, 37, 75
Effect of quenching.................53
Corrosion resistance (Continued)
Effect of reheat treating............52
Effect of strain hardening...........23
Effect of temper...................23
Faying surfaces................24, 26
Hydrogen peroxide.................21
Marine atmospheres................35
Nitric acid........................19
Salt water.............22, 24, 35, 41–2
Sulphur...........................21
Costs
Brazing costs.....................79
Casting dies......................58
Comparisons......................11
Steel.......................11, 44
Distribution costs.................11
Erection costs....................44
Fabrication costs...............11, 58
Finished article comparison..........11
Finishing costs...........9, 11, 58, 64
Machining costs...................58
Crystal structure..............45, 47, 48
Cutting compounds..................81
Cutting tools
Composition.......................81
Rake angles......................81

D

Definitions......................11, 88
Deflection characteristics...........16–17
Deoxidizing properties.............11, 21
Design....................53, 73, 78, 79
Design changes
Sheet to alclad sheet................42
Steel to aluminum...............16–17
Design problems....................68
Design stress.......................68
Die casting alloys........67 table 15, 106
Composition...............table 8, 94
Corrosion resistance...............26
Mechanical properties..17 table 15, 106
Die casting machines................58
Die castings...............photo, 66; 67
Corrosion resistance................67
Dimensional accuracy..............67
Dimensional stability...............67
Dimensional tolerances.............58
Fabrication equipment..............58
Finishing......................58, 67
Light weight......................67
Die forgings.........................43
Dimensional tolerances.............43
Die quenching.......................77
Die steel...........................67
Dies.........................58, 77
Costs...........................58
Dimensional accuracy.............30, 67
Dimensional stability................67
Dimensional tolerances......34, 43, 58, 64
Dimensions........................88
Distortion.......37, 38, 53, 55, 73, 77, 78
Drawing.........................72–4
Drawn tubing
Diameter tolerances.......table 33, 128
Drilling............................81
Drop forgings.......................43
Ductility....................59, 61, 72
Effect of alloying..............12, 13
Effect of artificial aging............48
Effect of cold working........11, 12, 37

E

Electric arc welding............77, 78, 79
Electric ovens......................55
Electric seam welding..........photo, 74
Electrical conductivity................9; 15 table 9, 95 table 10, 96

Electrical conductivity (Continued)
Effect of alloying . . . 13, 15
Effect of elements in solid solution . . . 15
Electrolytic action . . . 41
Electrolytic potential . . . 79
Electrolytic process . . . 9
Elongation . . . 12, 31, 47, 48, 88
Decrease by aging . . . 31
Effect of heat treating . . . 47, 48
Endurance limits . . . 35, 38, 88
Eutectic melting . . . 51
Extruded bar
Commercial tolerances . . . table 32, 125–7
Extruded rod
Commercial tolerances . . . table 32, 125–7
Extruded tubing
Commercial tolerances . . . table 34, 130–2
Extrusion alloys . . . 44
Extrusions . . . 30; photo, 36; 38, 39, 44–5; table 1, 89
Applications . . . 44
Commercial tolerances . . . table 32, 125–7
Comparisons with structural steel . . . 44
Corrosion resistance . . . 45
Cost comparisons . . . 44
Impact resistance . . . 44
Mechanical properties specifications . . . tables 20–4, 112–7
Section thickness . . . 44
Weight saving . . . 44

F

Fabricating properties . . . 9, 11, 13, 34, 72
Fabrication . . . 13, 29, 30, 71–83
see also Forgings—Fabrication; Plate—Fabrication; Sheet—Fabrication
Booklets . . . 71
Standardization . . . 30
Faying surfaces . . . 24, 26
Files . . . 81
Fillet joints . . . 78
Finishing . . . 9, 30, 82–3
Finishing costs . . . 9, 11, 58, 64
Flat plate
Commercial thickness . . table 26, 119–20
Maximum commercial sizes . table 42, 139
Standard sizes . . . table 35, 133–4
Flat sheet
Commercial sizes . . . table 36, 135; table 38, 137; tables 40 and 41, 138; table 43, 139
Commercial thickness . . . table 17, 110; table 26, 119–20
Maximum commercial sizes . table 42, 139
Sheared
Width tolerances . . . table 27, 121
Standard sizes . . . table 35, 133–4
Flattened and slit wire
Commercial sizes . . . table 55, 153
Commercial tolerances . . . table 31, 124
Flattened wire
Commercial sizes . . . table 55, 153
Commercial tolerances . . . table 31, 124
Flattening operations . . . 48
Flux . . . 77
Foil . . . 39
Fabrication . . . photo, 32
Forging alloys . . . 25, 42–3
Forgings . . . 39, 42–3; table 1, 89
see also Die forgings; Press forgings
Applications . . . 43
Aircraft propeller blades . . . photo, 18; photo, 40
Corrosion resistance . . . 25, 43
Fabrication . . . 13; photo, 40
Mechanical properties specifications . . . table 18, 111
Quenching . . . photo, 54
Forming . . . 24, 26, 37, 38, 71–3, 75, 77
Working radius . . . 73, 75
Forming properties . . . 11, 12, 34, 35, 75
Forming temperatures . . . 77
Forming tools . . . 73
Foundry factors . . . 68
Free-cutting machining properties . . . 39
Furnace brazing applications
Gasoline tanks . . . photo, 80
Furnaces
see also Ovens
Air furnaces . . . 51–2, 55
Holding furnaces . . . photo, 56
Pyrometric control . . . 51–2
Fusion welding . . . 24–5

G

Gas ovens . . . 55
Gas welding . . . photo, 76; 78
Comparison with brazing . . . 79
General-purpose castings . . . 59, 65
Guaranteed properties . . . 17, 19

H

Handstoning . . . 81
Hard temper properties . . . 30
Hardening constituents . . . 15, 45, 47, 48
Copper . . . 15, 60
Magnesium . . . 60
Precipitation . . . 48
Silicon . . . 15, 59, 60
Solid solution . . . 33, 45, 47, 48
Zinc . . . 60
Hardness
Effect of alloying . . . 11
Effect of heat treating . . . 12, 47, 48
Increase by cold working . . . 29
Heading tools . . . 82
Heat-treatable alloys . 12, 31, 35, 37–9, 49, 68
Aging . . . 37, 38
Annealing . . . 49–50
Applications . . . 37
Cold working . . . 37
Commercial forms . . . 37
Corrosion resistance . 23, 35, 37, 38, 39, 78
Distortion . . . 37, 38
Ductility . . . 37
Effect of heating . . . 78
Elongation properties . . . 12
Endurance limit . . . 38
Formability . . . 35, 38
Forming . . . 37
Hot forming . . . 37, 75
Machinability . . . 35, 39
Mechanical properties . . . 39, 61, 81
Quenching . . . 37, 38–9
Reheat treating . . . 37
Riveting . . . 81
Room temperature aged properties . . . 48
Storing . . . 37
Strength . . . 35, 37
Effect of welding . . . 78, 81
Tensile strength . . . 37, 38
Welding . . . 78
Workability . . . 37
Yield strength . . . 37, 38
Heat-treatable coiled sheet
Maximum commercial widths . . . table 44, 139
Heat-treatable flat sheet
Commercial sizes . . . table 40, 138
Heat-treatable plate
Forming . . . 77
Maximum commercial sizes . . . table 47, 144–5; table 48, 146–7
Mechanical properties . . . 77
Heat treated castings . . . 57–8
Heat treated sand castings . . . 61, 63–4
Heat treated temper designations . . . 33

Heat treatment....12, 23, 31, 45–56, 57–8, 61, 63–4, 67, 68; table 3, 91
Effect on corrosion resistance......24–6
Heat treatment applications
Propeller blades.............photo, 46
Heat treatment equipment
Air furnaces........................51
Heat treatment materials
Baths........................51, 53
Molten salt baths...............51, 53
Heat treatment process control........68
Heat treatment temperatures......45, 47; 50–2 table 3, 91; 77
Room temperature...............47–8
High-carbon steel...................45
High-carbon tool steel...............81
High-speed steels...................81
High strength alloys...23–6, 34, 35, 37, 38
Annealed........................25
Corrosion resistance..............23–6
Fusion welding..................24–5
Heat treating.....................23
Hot forming.....................24–5
Hot riveting.....................24–5
Quenching....................23, 24
Reheat treating.................23, 24
High temperature aging...........31, 55
also see Artificial aging
High temperature properties.............
...................19 table 16, 107–9
High velocity sprays..................53
Holding furnaces..............photo, 56
Hot driven rivets....................82
Hot forming..........24, 26, 37–8, 75, 77
Effect on corrosion resistance........75
Hot steel rivets.....................82
Hot working....................30, 47
Hydrogen peroxide...................21

I

Impact extrusions................39, 44
Applications.....................44
Fabrication.............photo, 36; 44
Impact loads....................17, 63
Impact resistance.................59, 63
Effect of artificial aging............48
Ingots..........................29, 30
Inhibitors.........................21
Instantaneous annealing temperature 48, 49
International Annealed Copper Standard 15

J

Joining methods—see Brazing; Riveting; Welding Joints
Design.......................78, 79
Mechanical type..................79

K

Kerosene..........................81

L

Lacquer finishing....................83
Lap joints.........................78
Lapping...........................81
Lard oil...........................81
Lathe tools........................81
Light alloys........................33
Lo-Ex alloy........................65
Lubricants (forming)................73
Lubricants (machining)...............81

M

Machinability.............34, 35, 39, 80
Machine-spinning.............photo, 70
Machining......................80–1
Machining costs....................58
Machining feeds and speeds...........81
Machining tools....................81
Manufacturing problems..............13
Marine atmospheres.................35
Mass conductivity...................15
Maximum commercial sizes.............
....................tables 45–8, 140–7
Maximum commercial widths.table 44, 139
Mechanical properties...........13, 19; 33–4 tables 12–15, 99–106; 38, 39, 41–2, 43, 57, 67–8
Effect of
Cold working................12, 30
Heat treating..........12, 31, 45–55
Salt water.................22, 41–2
Temperature....................19
Mechanical properties specifications......
.................tables 17–25, 110–18
Mechanical type joints...............79
Metal cores........................64
Metal oil..........................73
Metal molds....................58, 64
Milling...........................81
Mineral oil........................73
Minimum properties..............17, 19
Modification process.............59, 60
Modulus of elasticity........16–17, 19, 88
Comparison with steel.............16
High temperature effect............19
Modulus of rigidity...............17, 88
Mold design problems................58
Molten alloys.............45; photo, 56
Molten salt baths................51, 53

N

Nitrate baths......................51
Nitric acid........................19
Nominal composition.....tables 5–8, 92–3
Nonheat-treatable alloys............34–5
Applications.....................34
Corrosion resistance...............35
Cost............................34
Endurance limit..................35
Fabricating properties.............34
Mechanical properties.............35
Strength.......................34–5
Tensile strength...............34, 35
Welding.........................77
Workability....................34–5
Yield strength.................34, 35
Non-magnetic characteristic...........11
Non-sparking characteristic...........11
Non-toxic characteristic..........11, 21

O

Oil as quenching medium.............53
Organic grease solvents..............82
Ovens............................55
Oxide film........................77
Oxyacetylene flame..................78
Oxyhydrogen flame..................78

P

Paint..................23, 24, 26, 82–3
Pattern equipment...................58
Permanent mold casting alloys
Composition..........64–5 table 7, 94
Mechanical properties.17 table 14, 103; 64
Physical properties..64–5 table 10, 96–7
Selection........................64
Typical tensile properties..table 16, 108
Permanent mold castings.......photo, 62; 63, 64–5, 67
Applications.....................65
Cooking utensils................65
Flatiron soleplates..............65
Pistons........................63
Comparisons
Die castings....................58
Sand castings................58, 64

Permanent mold castings (Continued)
Composition....................57
Cost....................64
Dimensional tolerances..........58, 64
Fabrication equipment.......57, 58, 64
Finishing....................58, 64
Heat treated....................67
High temperature properties....................19 table 16, 108
Metallurgical properties............64
Permanent molds....................57
Phosphoric acid....................82
Physical properties......15–17, 19, 41, 45; table 10, 96–7
Effect of heat treating.............51
Pipe....................table 1, 89
Commercial tolerances.....table 33, 129
Piston alloys....................65
Plate.............30, 37, 39; table 1, 89
see also Alclad plate; Flat plate; Tread plate
Commercial tolerances...table 27, 121–2
Corrosion....................25
Fabrication....................13
Maximum commercial sizes....................tables 45 and 46, 140–3
Mechanical properties specifications.. table 17, 110; tables 21 and 22, 113–14; tables 24 and 25, 117–18
Sawed
Dimensional tolerances..table 27, 122
Sheared
Width and length tolerances.table 27, 122
Sizes.39 tables 45–8, 140–4 table 50, 148
Plate circles
Sheared
Diameter tolerances.....table 27, 121
Poisson's ratio....................17, 88
Precipitation heat treatment....31, 49, 55, 61, 77
Equipment....................55
Temperatures....................55
Press forgings.............photo, 36; 43
Dimensional tolerances.............43
Finishing....................43
Presses....................photo, 28
Pressings....................39
Pressure-die-casting machines..........58
Primers....................83
Properties..9–13, 17, 19, 68–9; table 9, 95
see also Chemical properties; Mechanical properties; Physical properties; Specified properties; Typical properties
Effect of alloying.........11, 12–13, 57
Uniformity....................30
Pure aluminum
Properties..................11, 15, 16
Pyrometric control................51–2

Q

Quenching...23, 24, 37, 38, 47, 50, 51, 53, 73, 77
Quenching baskets.............photo, 54
Quenching mediums..................53
Air blast....................52, 53
Oil....................53
Water....................53
Quenching rates....................53
Quenching tanks...........53; photo, 54

R

Recrystallization.................45, 49
Reducing agents....................11
Reflectivity....................9
Reheating.......23, 24, 25, 26, 37, 77, 78
Reheating temperatures..............24
Resistance to corrosion—see Corrosion resistance
Resistance welding..................79
Resistance welding equipment.........79
Rivet alloys....................81–2
2S....................81–2
17S....................35, 82
Reheat treating..................82
A17S-T....................82
53S....................82
53S-T61....................82
53S-W....................82
Riveted alclad sheet assemblies
Corrosion resistance..............41–2
Protection....................41
Salt spray test.................41, 42
Strength....................42
Riveted assemblies
Painting....................82
Riveting....................81–2
Hot riveting..................24, 26
Rivets..........35, 39, 41, 42; table 1, 89
Rod................30, 39; table 1, 89
Applications....................45
Centerless ground rod
Commercial tolerances...table 29, 124
Cold finishing....................30
Commercial sizes.......39 table 53, 152
Commercial tolerances...table 29, 123–4
Hot working....................30
Mechanical properties specifications.. table 19, 111; table 20, 112; table 22, 114; table 23, 116; table 25, 118
Tempers..................table 4, 92
Rolled bar
Commercial tolerances.....table 29, 123
Rolled round rod
Commercial tolerances.....table 29, 123
Rolled shapes.............30; table 1, 89
Rolled structural shapes
Commercial tolerances.....table 28, 122
Round tubing
Commercial sizes.......table 52, 150–1
Diameter tolerances.......table 33, 128
Length tolerances.........table 33, 129
Straightness tolerances....table 33, 129
Wall thickness tolerances..table 33, 128

S

Salt water..............22, 24, 35, 41–2
Sand....................68
Sand casting alloys...59–64 table 10, 96–7
Composition...............table 6, 93
Mechanical properties..17 table 13, 100
Selection..................59–61, 63
Typical properties.......table 10, 96–7
Typical tensile properties..table 16, 109
Sand castings...............59–61, 63–4
Applications
Aircraft....................63
Chemical plants..................60
Cooking utensils..................60
Crank cases....................63
Cylinder heads..................63
Dairy equipment..................60
Diesel engine castings............63
Internal-combustion engines.......63
Liquid-cooled engine castings......63
Marine castings..................60
Pump cylinder housings...........63
Sewage disposal plants............60
Fabrication equipment.............58
Finishing....................58
Heat treated...............61, 63–4
High temperature properties....................19 table 16, 109
Leak resistance.................59, 60
Precipitation heat treating..........61

Sand castings (Continued)
Pressure tightness..............60, 63
Solution heat treating..............61
Typical properties.......15 table 10, 96
Sand cores..........................64
Sand molds..........................58
Sawed plate
Dimensional tolerances....table 27, 122
Sawed sheet
Dimensional tolerances....table 27, 122
Sawing..............................81
Saws................................81
Scrap value.........................11
Screw machine products...........39, 45
Seam welding........................79
Seam welding applications
Aircraft....................photo, 74
Section thickness.............16–17, 68
Semi-permanent-mold castings...photo, 62
Fabrication equipment..............64
Sand cores.........................64
Sheared flat sheet
Width tolerances..........table 27, 121
Sheared plate
Width and length tolerances.table 27, 122
Sheared plate circles
Diameter tolerances.......table 27, 121
Sheared sheet circles
Diameter tolerances.......table 27, 121
Sheet..............30, 37, 39; table 1, 89
see also Alclad sheet; Coiled sheet; Flat sheet
Bend radii...............73 table 2, 90
Commercial sizes.39 tables 36–44, 135–9
Commercial tolerances...table 27, 121–2
Corrosion..........................25
Fabrication........................13
Heat treating......................55
Mechanical properties specifications......table 17, 110; tables 21 and 22, 113–14; tables 24 and 25, 117–18
Protection.....................25, 26
Sawed
Dimensional tolerances..table 27, 122
Thin sheet
Corrosion resistance..............53
Quenching.........................53
Sheet circles
Sheared
Diameter tolerances.....table 27, 121
Sodium nitrate baths.................51
Soldered joints
Corrosion resistance...............80
Soluble cutting oils..................81
Solution heat treated alloys
Strength......................31, 33
Solution heat treatment........24, 31, 38, 47, 48, 50–3, 55, 61, 78
Solvent cleaning.....................82
Special foundry practices.........59, 63
Specific gravity..................11, 13; 15 tables 9 and 10, 95–7
Effect of alloying.................13
Specified properties.................13; 17 tables 17–25, 110–18
Spinning.............................72
Spot welding.........................79
Squares and rectangles
Commercial sizes.........table 54, 153
Commercial tolerances.....table 30, 124
Stabilization of dimensions.........64, 65
Stamping.........................71, 73
Standard sizes..........table 35, 133–4; table 49, 148
Standardization......................30
Steam coils..........................55
Steel............................35, 44
see also Die steel; High carbon steel

Steel (Continued)
Coefficient of thermal expansion.....16; table 11, 98
Comparisons................11, 12, 16
Deoxidizing....................11, 21
Machining..........................81
Resistance welding.................79
Section thickness...............16–17
Welding........................77, 78
Steel and aluminum assemblies........16
Steel dies...........................77
Steel forming tools..................73
Steel rivets.........................82
Storage..........................37, 38
Strain hardening...........12, 23, 29, 30, 31, 48, 49, 50
Strength........17, 34, 35, 37, 38, 47, 48, 60, 63, 65
Comparisons
Steel............................12
Effect of
Aging...........................31
Alloying.....................11, 12
Artificial aging................48
Cold working..........11, 12, 29, 33
Heat treating............12, 47, 48
Marine atmosphere...............24
Strain hardening..........12, 33, 35
Stress reduction.....................17
Structural design.................44, 49
Structural sections
Angles.............................77
Beams...........................16–17
Corrosion resistance.............25–6
Structural shapes.........39 table 51, 149
Commercial sizes.........table 51, 149
Commercial tolerances.....table 28, 122
Mechanical properties specifications.............table 20, 112; table 22, 115; table 23, 116; table 25, 118
Structural steel.....................44
Sulphur..............................21
Supersaturated solid solutions......47, 48
Surface preparation................82–3
Surface protection...........25, 26, 82–3

T

Tallow...............................73
Temper designations...........29–31, 33
H..................................30
O..............................29, 30
RT.................................33
T......................31, 33, 48, 72
T3.................................33
T5.................................33
T80................................33
T81............................33, 37
T86............................33, 37
W......................31, 33, 48, 72
Temperature control................50–2
Temperatures................24, 45, 47; 50–2 table 3, 91; 55, 77
Tempers........24, 29–31, 33; table 4, 92
Artificially aged tempers............31
Control............................30
Effect of heating...................78
Effect on corrosion resistance......22–3
Hard temper........................30
Heat-treatable tempers.............50
Intermediate tempers...............30
Room temperature aged tempers.....31
Soft tempers...................29, 30
Tensile strength.......11, 12, 13, 29, 30, 31, 34, 35, 37, 38; table 16, 107–9
Effect of
Aging.......................25, 31
Alloying....................13, 33
Cold working....................37

Tensile strength (Continued)
Heat treating..............12, 48, 49
Strain hardening.................29
Temperature......19 table 16, 107–9
Terminology........................88
Test bars.......................17, 58
Metal mold cast bars...............58
Sand cast bars.....................58
Test specimens
A. S. T. M......................67–8
Control specimens..................42
Mechanical test specimens..........41
Properties......................68–9
Riveted tensile test specimens.......42
Testing..................photo, 14; 19
Tests...........................24, 42
Salt spray test...................41–2
Thermal conductivity.................9; 16 tables 9 and 10, 95–6
Effect of alloying..................13
Thermal expansion........16 table 11, 98
Thermit welding process..............22
Tool steel...........................73
Tools
Forming tools......................73
Heading tools......................82
Machining tools....................81
Torch welding.........photo, 75; 78, 79
Tread plate
Commercial sizes.........table 50, 148
Tubing...............30, 39; table 1, 89
Applications
Hypodermic needles.............39
Ship masts......................39
Commercial tolerances.....table 33, 128
Fabrication........................13
Mechanical properties specifications.............table 20, 112; table 22, 115; table 25, 118
Sizes....39 table 49, 148 table 52, 150–1
Twist drills.........................81
Typical mechanical properties.........................17 tables 12–15, 99–106
Typical properties...tables 9 and 10, 95–7
Typical tensile properties..table 16, 107–9

U

Ultimate tensile strength.............49

V

Vanadium.............................21
Volume conductivity..................15

W

Warping..............................73
Washing..............................53
Water as quenching medium...........53
Wear resistance..................63, 65
Weight.9, 13, 15; table 9, 95; table 10, 96–7
Effect of alloying..................13
Weight saving.................17, 44, 67
Weld beads...........................78
Weldability.......................9, 34
Welded joints......................78–9
Corrosion resistance...............80
Welding............24–5, 26; photo, 74; photo, 76; 77–9
see also Arc welding; Gas welding; Seam welding; Spot welding
Welding flux.........................77
Welding rod........................77–8
Welds................................78
Wet chemical process..........photo, 10
Wire.............30, 35, 39; table 1, 89
Centerless ground wire
Commercial tolerances...table 29, 124
Commercial sizes......39 table 53, 152; table 55, 153

Wire (Continued)
Commercial tolerances..table 29, 123–4; table 31, 124
Mechanical properties specifications.............table 20, 112; tables 22 and 23, 114–16; table 25, 118
Wrought alloys................13, 29–55
2S
Annealing..........................49
Applications...................26, 34
Bar......................table 4, 92
Brazing............................80
Coiled sheet widths.....table 37, 136
Commercial forms...................30
Commercial thickness tolerances..........................table 26, 119
Corrosion resistance.......22, 23, 24, 26, 43, 45
Cost...............................34
Drawing..........................71–2
Fabricating properties.............34
Flat sheet sizes.........table 36, 135
Forging............................71
Formability......................71–2
Mechanical properties.17 table 12, 97; 72
Mechanical properties specifications..........................table 17, 110
Pipe....................table 33, 129
Plate.....table 17, 110; table 26, 119
Plate sizes...........table 45, 140–1
Press forgings.....................43
Riveting.........................81–2
Rivets.............................81
Rod......................table 4, 92
Sheet.....table 17, 110; table 26, 119
Spinning.........................71–2
Stamping...........................71
Strength.....................34–5, 45
Tempers.........................29–30
Weldability........................43
Welding rod........................77
Workability......................34–5
2S-½H
Tubing sizes...........table 49, 148
2S-O
Ductility..........................72
Formability........................72
3S
Annealing..........................49
Applications...................26, 34
Bar......................table 4, 92
Brazing............................80
Coiled sheet widths.....table 37, 136
Commercial forms...................30
Commercial thickness tolerances..........................table 26, 119
Corrosion resistance.22, 23, 24, 26, 45
Cost...............................34
Fabricating properties.............34
Flat sheet sizes.........table 36, 135
Mechanical properties..............72
Mechanical properties specifications..........................table 17, 110
Pipe....................table 33, 129
Plate.....table 17, 110; table 26, 119
Plate sizes...........table 45, 140–1
Riveting.........................81–2
Rod......................table 4, 92
Sheet.....table 17, 110; table 26, 119
Strength.....................34–5, 45
Tempers.........................29–30
Workability......................34–5
3S Alclad
Sheet..............................42
Tubing.............................42

Wrought alloys (Continued)
3S-O
Ductility....................72
Formability....................72
11S
Bar....................table 19, 111
Machinability....................39
Mechanical properties....................39
Mechanical properties specifications....................table 19, 111
Rod....................table 19, 111
11S-T3
Automatic screw machine stock....39
Machinability....................39, 45
Rod....................45
14S
Cold working....................48
Corrosion resistance....................23, 25
Extrusions....................table 21, 113
Flat sheet sizes....................table 43, 139
Forgings....................43
Mechanical properties specifications....................table 21, 113
Plate....................table 21, 113
Room temperature aged tempers...31
Sheet....................table 21, 113
Tempers....................31
14S Alclad
Plate and sheet....................table 26, 120
14S-T....................25–6
Applications....................26
Extrusions....................44
Forgings....................43
Mechanical properties....................43
Quenching....................25–6
14S-W
Corrosion resistance....................26
Hot forming....................75
17S
Age hardening....................35
Applications....................35
Bar....................table 20, 112
Corrosion resistance..23, 24, 26, 52–3
Extrusions..........44; table 20, 112
High temperature aging....................31
Machinability....................35
Mechanical properties specifications....................table 20, 112
Quenching....................52–3
Rivets....................35, 82
Rod....................table 20, 112
Room temperature aged tempers...31
Strength....................31
Structural shapes.......table 20, 112
Tempers....................31, 33
Tubing....................table 20, 112
Wire....................table 20, 112
Workability....................35
A17S
Corrosion resistance....................52–3
Quenching....................52–3
17S-O
Heat treating....................52
17S-T
Applications....................43
Cold working....................33
Corrosion resistance....26, 35, 43, 75
Forgings....................43
Mechanical properties..........35, 39
Riveting....................82
Rivets....................42, 82
Strength....................35
Tempers....................33
Yield strength....................33
17S-T Alclad
Sheet....................42

Wrought alloys (Continued)
18S
Forgings....................43
24S
Age hardening....................37
Applications....................26, 35, 37
Artificial aging..........31, 33, 37, 48
Bar....................table 22, 114–5
Blistering....................51
Cold working....................31, 33, 37
Commercial forms..35 table 1, 89; 37
Corrosion resistance.......23, 25, 26, 37, 38, 48, 52–3
Distortion....................38
Ductility....................37
Extrusions....................table 22, 115
Flat sheet sizes..........table 41, 138
Heat treatable plate sizes....................table 47, 144–5
Heat treating..........31, 33, 51, 55
High temperature aging....................31
Hot forming....................37
Mechanical properties....................38
Mechanical properties specifications....................table 22, 114–5
Plate..42; table 22, 114; table 26, 120
Products..........35 table 1, 89; 37
Protection....................51
Quenching..........23, 37, 38–9, 52-3
Reheat treating....................37
Rod....................table 22, 114
Room temperature aging.......31, 37
Sheet..........42, 53; table 22, 114; table 26, 120
Storage temperatures....................37
Strength........31, 33, 34, 35, 37, 48
Structural shapes.......table 22, 115
Tempers....................31, 33
Tubing....................table 22, 115
Wire....................table 22, 114–5
Workability....................37
24S Alclad
Applications....................37
Artificial aging....................23, 49
Corrosion resistance.......23, 25, 26, 38, 49, 53
Flat sheet sizes..........table 41, 138
Heat treated....................49
Plate....................table 26, 120
Protection....................51
Quenching....................53
Reheat treated....................49
Sheet....................table 26, 120
Strength....................23, 37
24S-O
Heat treating....................52
Workability....................38
24S-RT
Bend radii....................72
Flat plate and sheet sizes.table 42, 139
Formability....................72
24S-RT Alclad
Flat plate and sheet sizes.table 42, 139
24S-T
Artificial aging....................37
As quenched....................49
Chemical properties....................45
Cold working....................33
Corrosion resistance.25, 26, 37, 49, 75
Distortion....................37
Extrusions....................44
Formability....................72
Hot forming....................37, 75
Physical properties....................45
Reheat treating....................52, 75
Riveting....................82
Screw machine products....................45

Wrought alloys (Continued)
24S-T (Continued)
Strength....37
Tempers....37
Tubing sizes....table 49, 148
Workability....37, 72
Yield strength....33
24S-T Alclad
Corrosion resistance....25
Sheet....42, 49
Strength....37
Workability....37
24S-T80....33
24S-T81....33, 37
24S-T86....33, 37
25S
Forgings....43
32S
Coefficient of thermal expansion....43
Forgings....43
A51S
Applications....43
Forgings....43
52S
Annealing....49
Coiled sheet widths....table 39, 137
Commercial forms....30
Corrosion resistance....22, 24, 35
Ductility....72
Endurance limit....35
Flat sheet sizes....table 38, 137
Mechanical properties....72
Mechanical properties specifications ....table 17, 110
Plate....table 17, 110; table 26, 120
Plate sizes....table 46, 142–3
Riveting....82
Sheet....table 17, 110; table 26, 120
Strength....34–5
Tempers....29–30
Workability....34–5
52S-O
Tubing sizes....table 49, 148
53S
Age hardening....38
Applications....24
Bar....table 23, 116
Cold working....48
Cooling rates....55
Corrosion resistance. 24, 26, 38, 39, 55
Extrusions....44–5; table 23, 116
Formability....38, 72
Heat treating....38
Mechanical properties specifications ....table 23, 116
Quenching....38–9
Rivets....82
Rod....table 23, 116
Strength....38
Structural shapes....table 23, 116
Tempers....31
Wire....table 23, 116
53S-T
Applications....43
Corrosion resistance....43, 75
Hot forming....75
Rivets....82
Strength....35
53S-T61
Rivets....82
53S-W
Hot forming....75
Rivets....82
56S
Mechanical properties....35
Strain hardening....35
Wire....35

Wrought alloys (Continued)
61S
Age hardening....38
Applications....24
Artificially aged tempers....31
Bar....table 25, 118
Brazing....80
Cold working....48
Cooling rates....55
Corrosion resistance....23, 24, 26, 38, 39, 45, 55
Extrusions....45
Formability....38, 72
Heat treatable plate sizes ....table 47, 144–5
Heat treating....38
Mechanical properties specifications ....table 25, 118
Plate....table 25, 118; table 26, 120
Quenching....38–9
Rod....table 25, 118
Sheet....table 25, 118; table 26, 120
Strength....38
Structural shapes....table 25, 118
Tempers....31
Tread plate sizes....table 50, 148
Tubing....table 25, 118
Wire....table 25, 118
Workability....72
Yield strength....45, 72
61S-T
Corrosion resistance....75
Hot forming....75
61S-W
Hot forming....75
75S
Aging....55
Cold working....48
Corrosion resistance....23, 25, 26
Extrusions....38, 44, 55; table 24, 117
Flat sheet sizes....table 43, 139
Heat treatable plate sizes ....table 47, 144–5
Heat treating....55
Mechanical properties specifications ....table 24, 117
Plate....table 24, 117; table 26, 120
Quenching....38–9, 55
Sheet....table 24, 117; table 26, 120
Strength....34, 35, 38
75S Alclad
Corrosion resistance....25, 26
Flat sheet sizes....table 43, 139
Plate....table 26, 120
Sheet....38, 42; table 26, 120
75S-T
Corrosion resistance....25
Endurance limit....38
Extrusions....44
Formability....38
Strength....38, 44
Structural applications....44
75S-T Alclad
Formability....38
Strength....38
75S-W
Formability....38
Hot forming....75
Aging....31, 72, 73, 77
Alloying elements....12, 33
Annealing....29, 30
Applications....34, 37, 39
Artificial aging....24, 31, 33
Bend radii....72, 73
Chemical properties....45
Coefficient of thermal expansion....43; table 11, 98

Wrought alloys (Continued)
Cold working.........29–30, 31, 33, 72
Commercial forms.30; 34 table 1, 89; 37
Composition...............table 5, 93
Controlled temper alloys............30
Corrosion resistance....22–7, 34, 35, 37, 38, 39
Effect of heating.............37, 75
Effect of temper................24
Salt water..................24, 35
Distortion........37, 38, 53, 55, 73, 78
Ductility.........................72
Electrical conductivity....15 table 9, 95
Elongation........................47
Decrease by aging................31
Endurance limits...............35, 38
Fabricating properties.............72
Fabrication........................29
Formability...........34, 71–3, 75, 77
Fusion welding..................24–5
Hardness.....................47, 48
Heat-treatable alloys.............35–9
Heat treating...12, 23, 29, 31, 45–55, 75
Heavy sections....................30
High temperature properties........19; table 10, 107–8; table 16, 107–8
Hot forming.......................24
Hot riveting.......................24
Hot working.......................30
Machinability...............35, 39, 80
Mechanical properties...17 table 12, 99; 22, 33–4, 39, 41–2, 43
Effect of heat treating.......31, 50–2
Mechanical properties specifications.... ..tables 17 and 18, 110–11; table 20, 112; tables 22–5, 114–18
Nonheat-treatable alloys..........34–5
Physical properties.................45
Effect of heat treating...........51
Precipitation heat treatment.....31, 77
Properties...............15 table 9, 95
Protective coatings................26
Quenching..23, 24, 25, 50, 51, 53, 73, 77
Reheat treating.........23, 24, 25, 26
Selection..........................72
Solution heat treating..............31
Specific gravity..........15 table 9, 95
Strain hardening.........29, 30, 31, 35

Wrought alloys (Continued)
Strength...................47, 48, 72
Effect of
Aging.........................31
Alloying......................12
Cold working..............12, 29
Strain hardening.........12, 33, 35
Tempers....................29–31, 33
Tensile strength.........12, 25, 33, 34, 42, 48, 49; table 16, 107–8
Effect of
Aging.........................31
Cold working..................37
Heat treating.................38
Strain hardening.........29, 30, 31
Thermal conductivity.....16 table 9, 95
Thin sections......................30
Typical mechanical properties......... ....table 12, 99
Typical properties..........table 9, 95
Typical tensile properties.table 16, 107–8
Ultimate tensile strength............49
Weight.................15 table 9, 95
Welding...........................78
Workability.......................35
Yield strength.................34, 49
Effect of
Aging.........................31
Cold working..................33
Heat treating.................38
Wrought products.13 table 1, 89; 39, 42–3
As fabricated products.............30
Controlled temper products.........30
Dimensions........................88
Heavy sections....................30
Thin sections.....................30

Y

Yield strength.......12, 13, 34, 37, 38, 88
Effect of
Aging.........................31
Alloying......................13
Cold working...............33, 37
Heat treating............12, 48, 49
Temperature...................19

Z

Zinc...............................26
Zinc chromate primer...............83

sales offices

AKRON 8, OHIO	506 Akron Savings & Loan Building
ALBANY 7, N. Y.	90 State Street
ATLANTA 3, GA.	1818 Rhodes-Haverty Building
BALTIMORE 1, MD.	400 Baltimore Life Building
BIRMINGHAM 3, ALA.	619 First National Building
BOSTON 16, MASS.	20 Providence Street, Park Square
BUFFALO 7, N. Y.	1880 Elmwood Avenue
CHARLOTTE 2, N. C.	815 Johnston Building
CHICAGO 11, ILL.	520 North Michigan Avenue
CINCINNATI 2, OHIO	16th Floor, Times-Star Building
CLEVELAND 1, OHIO	1520 Midland Building
COLUMBUS 15, OHIO	526 Rowlands Building
DALLAS 1, TEXAS	821 Mercantile Bank Building
DAVENPORT, IOWA	918 Kahl Building
DAYTON 2, OHIO	302 Harries Building
DETROIT 2, MICH.	610 New Center Building
FAIRFIELD, CONN.	Post Road
GRAND RAPIDS 2, MICH.	812 Michigan National Bank Building
HARTFORD 3, CONN.	Capitol Building, 410 Asylum Street
HOUSTON 2, TEXAS	1806 Commerce Building
INDIANAPOLIS 4, IND.	817 Merchants Bank Building
JACKSON, MICH.	1407 National Bank Building
KANSAS CITY 6, MO.	2300 Power & Light Building
LOS ANGELES 14, CALIF.	108 West Sixth Street
LOUISVILLE 2, KY.	1154 Starks Building
MILWAUKEE 2, WIS.	735 North Water Street
MINNEAPOLIS 2, MINN.	1060 Northwestern Bank Building
NEWARK 2, N. J.	744 Broad Street
NEW ORLEANS 12, LA.	707 American Bank Building
NEW YORK 17, N. Y.	230 Park Avenue
OKLAHOMA CITY 2, OKLA.	1209 Apco Tower
PHILADELPHIA 9, PA.	123 South Broad Street
PITTSBURGH 22, PA.	District Sales—1814 Oliver Building
PITTSBURGH 19, PA.	General Offices—Gulf Building
PONTIAC 15, MICH.	508 Peoples State Building
PORTLAND 4, ORE.	512 Porter Building
PROVIDENCE 3, R. I.	1421 Industrial Trust Building
RICHMOND 19, VA.	213 Exchange Building
ROCHESTER 4, N. Y.	1331 Lincoln Alliance Bank Building
ST. LOUIS 8, MO.	10th Floor Continental Building
SAN FRANCISCO 4, CALIF.	615 Russ Building
SEATTLE 1, WASH.	1411 Fourth Avenue Building
SOUTH BEND 5, IND.	805 J.M.S. Building
SPRINGFIELD, ILL.	716 Reisch Building
SPRINGFIELD 3, MASS.	507 Tarbell-Watters Building
SYRACUSE 2, N. Y.	1014 State Tower Building
TAMPA 2, FLA.	401 Tampa Theater Building
TOLEDO 4, OHIO	1801 Ohio Building
TULSA 3, OKLA.	414 Central Building
WASHINGTON 5, D. C.	605 Southern Building
WICHITA 2, KAN.	411 Fourth National Bank Building
WILMINGTON 50, DEL.	310 Pennsylvania Building
YORK, PA.	2 North Beaver Street

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